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HEAVY MINERAL STUDIES ON CORRELATION OF
SANDS AT KETTLEMAN HILLS, CALIFORNIA¹

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ABSTRACT

The data and results from a petrographic study of 400 core and outcrop samples of Miocene and Pliocene sandstones from this region are presented. The mineral zones delimited suggest some peculiar stratigraphic variations and relations and seem to agree with the scanty paleontologic evidence available. The main point is a corroboration of the view that most of the upper 600 feet of producing sands in the field have very little development in the outcrops, and that most of the sandstone at the outcrops, referred to the Temblor, represents strata encountered at depths of about 1,000 feet in the producing zones. The method of laboratory procedure is briefly outlined, and some discussion is presented on the mineral zones and on individual minerals of particular significance.

INTRODUCTION

The United States Geological Survey has been engaged in recent years in a study of the surface and subsurface geology of the Kettleman Hills oil field, which lies on the west side of the San Joaquin Valley, California. As part of this project the writer has undertaken a study of the petrography of the sands as an aid in correlation. The meager macro- and micro-faunas have limited the usefulness of paleontologic correlations, and although the lithologic units are fairly satisfactory for a correlation from well to well, variations make them of doubtful value for comparison of wells in the North dome with those of the Middle dome or with the outcrops in Reef Ridge. The results of

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this petrographic study indicate that, though the sediments of this area are not susceptible to as close a differentiation of stratigraphic horizons on the basis of their mineral content as those in some other regions, certain distinctive mineral zones that aid in correlation are present and lend support to other lines of evidence on the correlations. The location of the outcrop and well sections represented on the correlation chart is shown on the sketch map (Fig. 1).

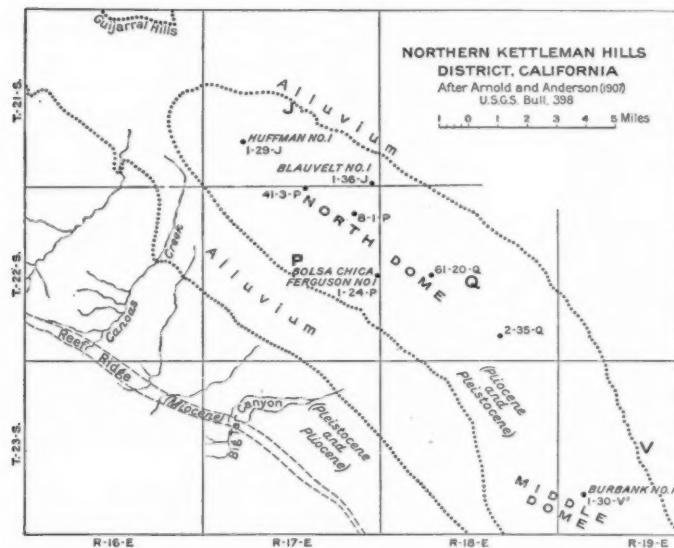


FIG. 1

The general geology and stratigraphy of this area were described in 1910 by Arnold and Anderson.³ A brief review of present ideas on the surface and subsurface stratigraphy has been presented in a recent book by Reed,⁴ and a more detailed discussion of the Kettleman Hills by Gester and Galloway,⁵ with their interpretation of the stratigraphic relations, has recently been published in this *Bulletin*. A paper

³ Ralph Arnold and Robert Anderson, "Geology and Oil Resources of the Coalinga District, California," *U. S. Geol. Survey Bull.* 398 (1910).

⁴ R. D. Reed, *Geology of California* (Amer. Assoc. Petrol. Geol., 1933), pp. 217-20, 234-36.

⁵ G. C. Gester and John Galloway, "Geology of Kettleman Hills Oil Field, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 10 (October, 1933), pp. 1161-93.

by Goudkoff on the stratigraphy of the area has also appeared in this *Bulletin*.⁶

ACKNOWLEDGMENTS

Core samples from wells of the different companies were obtained through the generous coöperation of the companies. Particular thanks are due to W. F. Barbat, J. H. Sargent, Stanley Siegfus, Leo Fox, R. C. Ward, and H. H. Dievendorff. Helpful suggestions and information were kindly furnished by Ralph D. Reed and Paul P. Goudkoff.

METHOD OF PROCEDURE

In heavy-mineral work on sediments the procedure varies much with the individual worker and the conditions, but the essential point seems to be the necessity of a standardized procedure in any one project, in order that results may be comparable. The method used in this study is briefly outlined as follows. A preliminary breaking up of the sandstone samples by crushing is followed by treatment with dilute *HCl* on a hot plate to disintegrate the sand and by the addition of a small amount of *HNO₃* to dissolve the pyrite. The sample is then washed to remove all clay-size material and the finest silt. After drying, the sand is screened on an 80-mesh screen, and only the material passing through this screen, which includes the fine sand, very fine sand, and coarser silt (0.25–0.03 mm.), is retained for use. A measured amount of this sand is then treated with bromoform⁷ in the separatory funnel, and the proportion of the heavy-mineral residue thus obtained to the total sand is estimated by comparison with several samples determined more accurately by actual weighing of the two fractions.

Both the light-mineral fraction (specific gravity less than 2.85) and the heavy fraction (specific gravity greater than 2.85) were examined with the petrographic microscope in index of refraction immersion liquids. Mineral percentages were only estimated, with an occasional check by the counting of grains, and the data were tabulated as indicated in the accompanying sheets.

There are several points in this mode of procedure that affect the results, and the more important will be briefly considered. The acid treatment eliminates all apatite from the sand, along with the carbonates, and removes most of the phosphatic pellets or "sporbo." The dilute acid is not strong enough to affect the more stable minerals,

⁶ Paul P. Goudkoff, "Subsurface Stratigraphy of Kettleman Hills Oil Field, California," *ibid.*, Vol. 18, No. 4 (April, 1934), pp. 435–75.

⁷ The usual commercial bromoform contains a small percentage of alcohol, which must be removed by washing with water to bring the specific gravity up to about 2.85.

or the hornblende, augite, et cetera. A preliminary examination indicated that apatite is one of the more common heavy minerals throughout the section, and its relative abundance at different horizons, as in the case of the ubiquitous mineral zircon, is apparently of little correlative value. Phosphatic pellets occur abundantly at certain horizons, but if they are significantly abundant they can be noted

TABLE I

in a preliminary examination of samples under the binocular microscope. The pyrite is dissolved by the addition of HNO_3 in the acid treatment, as it may "flood out" other minerals in the heavy separate, and the advantages of eliminating this mineral seem to compensate for the loss of any small value it may give to local correlation in wells.

The effect of various features in the texture and grain size of a sand on the mineral composition has recently been emphasized by

Rubey.⁸ These features and their relations must be considered in any "ultimate" study of a sediment, and in well sorted and much abraded sediments, such as some of the Paleozoic sandstones, they may be of critical importance even in correlation. Experience indicates that in the rather poorly sorted sediments that constitute most Tertiary formations textural differences do not cause any serious complication in the variations of mineral percentages of sands. This is indicated by the characteristic assemblage shown by the individual samples within a

TABLE II

certain "mineral zone," regardless of considerable variation in sand size. A preliminary test of some of these relations indicated that though the fraction of medium-to-coarse sand showed a distinctly lesser percentage of heavy residue than the finer sand, the differences in relative abundance of individual minerals were not very great. The differences noted suggested that in these Miocene sediments the dis-

⁸ W. W. Rubey, "The Size Distribution of Heavy Minerals within a Water-Laid Sandstone," *Jour. Sed. Petrology*, Vol. 3, No. 1 (1933), pp. 3-29.

TABLE III

Big Tar Canyon Section	Light Minerals			Heavy Minerals			Mc Lure Shale
	Calcite	Bentonite	Quartz	Orthoclase	Acid Plag.	Amphibole	
BT-B-L	875635	7	0.3	878	41	2644	Sandy Shale (Mc Lure?)
BT-T-L	875635	4	0.2	878	41	2644	
BT-L-L	874527	2	0.6	87132	754351	173	
L-9A	874226	0.8	0.8	87122	754351	14	
L-10A	865727	4	0.8	87132	754352	123	
BT-Z-L	X44	5					Bentonite
L-22	X874538	4	0.2	784321	654251	1114121	
L-21	774637	0.4	0.8	82323	543512	21312	
L-20B	864627	0.5	0.6	23121	53612	24211	
L-20	X864728	0.7	2	22	256326	113426233	
L-19	774916	0.3	0.3	73	2	156323	
L-18	X7447158	0.5	0.6	356322	23114	344	
L-17	6648184	0.0	0.5	53	2	133212	
L-15	X7648174	0.2	0.2	73	3344325	114435114	
L-13	7658183	3.0	1	1533249	12428443		
L-12	7747184	1.0	0.2	72	1533241	3438423	
L-11	764728	1.0	0.2	72	2533225	23537453	
L-10	864718	3.0	0.2	72	233213	24229554	
L-9	774718	0.9	0.2	72	2433229	1343343	
L-8	X7536184	0.2	0.2	213234925	3537434		
L-7	7536185	0.3	0.3	12	345325	3427233	
L-X	642918	0.3	0.2	43	164425	237	
L-5	744718	0.1	0.3	33	54425	12363	
L-3	X854818	0.4	0.4	3221	434	1223	
L-1	864618	0.2	0.4	333346	533		
A-2	X864718	0.8	0.3	435555	4131		
L-A	854718	0.8	0.8	33326653	4232	3	Basal Tembler

TABLE IV

Ganoas Creek Section	Light Minerals			Heavy Minerals			Mc Lure Shale
	Calcite	Bentonite	Quartz	Orthoclase	Acid Plag.	Amphibole	
C-3A	764628	0.9	2.4	22	754251	13	Sandy Shale (Mc Lure?)
	X44						Bentonite
C-2A	874637	0.6	0.6	22	164425	1222	
C-18	865627	0.6	0.6	153244	2332	1	
C-17	X864737	0.8	0.8	22	266323	25	
C-5A	854738	0.6	0.5	43	365433	25	
C-16	675627	0.3	0.5	32	255434	134	
C-15	X864828	0.5	0.4	11	255426	114329	
C-14	7548283	0.7	0.3	22	243314	133229	
C-13	X7548283	3.0	0.3	22	254924	13438543	
C-12	7438277	2.0	0.2	21	2221	1	
C-11	864828	2.0	0.2	11	243214	2429553	
C-10	754828	1.5	0.2	11	133213	2429533	
C-9	X754828	4.0	0.2	21	344324	11264532	
C-7	764828	1.2	0.2	11	24313	11428454	
C-6	X855738	0.6	0.2	32	245425	13636323	
C-4	8548283	1.0	0.2	22	133213	2438564	
C-1	5439184	1.0	0.2	22	344314	262532	
Basal Tembler	853728	1.5	0.3	42	432322	75	Basal Tembler

tribution of different minerals was more a reflection of differences in size of the particles as derived from the source rocks than of differences due to differential abrasion or sorting. In using heavy minerals on stratigraphic problems, the large number of samples that must be examined make it impracticable to study each grade size separately, and experience indicates that such procedure is not generally necessary, though it may give some additional data, particularly in regard to the source materials. If the samples for study are collected by choosing sands of somewhat similar grain size, preferably fine sands, and a considerable range in size is used, the textural differences do not cause any serious complication in the variation of mineral percentages of the sands.

TABULATION OF DATA

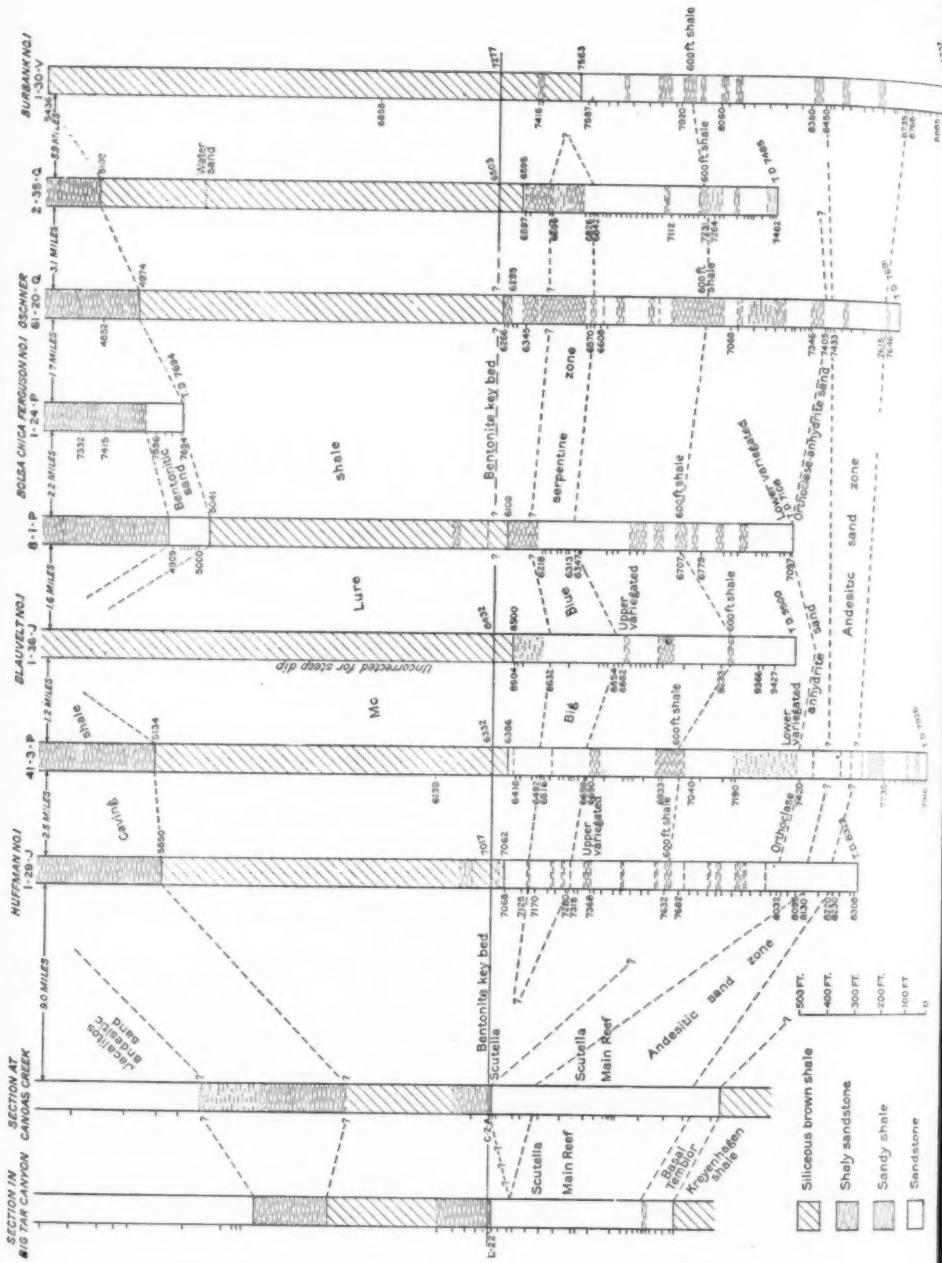
As indicated on the mineral data sheets, the percentages are given within certain ranges, arbitrarily selected by the writer to correspond with Milner's numerals of abundance,⁹ since the latter may have a very different quantitative significance to different workers. Closer accuracy in percentages seems unjustified in such a study, as the counts vary somewhat in each field of the same slide, and textural differences and other factors modify the percentages somewhat.

The percentages of the lighter minerals, represented in the numeral equivalents, are given in the first columns to the left on the data sheets, and the glauconite and phosphatic pellets are included in this section, though some of these occur in the heavy separate, particularly if the phosphatic pellets or "sporbo" are pyritic. A separate column gives the percentage of heavy residue (specific gravity greater than 2.85) as compared with the total sand. The percentages of the heavy minerals are then given, based on a 100 per cent total, like those of the lighter minerals. As this heavy mineral fraction is generally less than 1 per cent of the total sand, these percentages obviously represent very different absolute amounts from those represented by corresponding percentages in the light fraction.

Horizontal lines are drawn to separate the more clearly delimited mineral zones, and at the right of the sheet these more definite mineral zones and several of the lithologic units are given designations for use in the correlation chart.

These mineral data sheets are presented for the two outcrop sections and for two well sections in order to indicate the basis for the mineral zones delimited and used on the correlation chart. They give

⁹ Henry B. Milner, *Sedimentary Petrography*, 2d ed. (1929), pp. 386-88.



CORRELATION OF SANDS AT KETTLEMAN HILLS 1567

sufficient indication of the mineral character of the different zones, and presentation of the mineral data on the other well sections would unnecessarily enlarge this paper.

DISCUSSION OF MINERAL ZONES

Several rather distinctive mineral zones are delimited within the section containing intermediate zones of more uniform or nondescript character, and these mineral zones will be briefly described in ascending stratigraphic order.

Basal Temblor.—At the outcrops in Reef Ridge the Kreyenhausen shale is overlain by about 100 feet of sandstone of rather nondescript mineral character, in this feature distinct from the overlying andesitic sand zone. The mineral composition is given in the two outcrop sections and in the lower part of well section 41-3-P in the tables. In Big Tar Canyon there is a 10-15 foot sandy shale at the top of this zone. This sand is here classed as basal Temblor, though it may possibly include sands of Vaqueros (lower Miocene) age or even older beds, as there is little paleontologic evidence on the age of this basal zone. With the small amount of material available no attempt is made here to differentiate within these lower sands, and no mineral data are presented bearing on the relations of the shale locally called "Whepley shale" to the "Leda" zone and to typical Kreyenhausen. The evidence now available seems to indicate that the mineralogy at these lower horizons is so uniform that it would be of little value in their differentiation.

Andesitic sand zone.—The major part of the Temblor (middle Miocene) sandstones along Reef Ridge consists of a distinctive andesitic sand zone. In Canoas Creek and Big Tar Canyon this zone is about 500 feet thick and includes the "reef beds" containing *Turritella ocoyana* and most of the sand containing "buttons," or *Scutella merriami*, as indicated on the correlation chart. The mineral tabulations indicate that this zone is characterized by abundant andesine, much of which shows a good euhedral form with distinct zonal growth, many andesitic rock grains of finer texture, varying amounts of more or less altered shards of volcanic glass, and among the heavy minerals considerable amounts of green and basaltic (brown) hornblende, augite, and actinolite—the actinolite perhaps derived from hornblende. From the composition it is estimated that parts of this zone contain nearly 50 per cent of andesitic pyroclastic materials, mixed with the ordinary clastic sands. This mineral zone is sharply delimited from the basal Temblor and from overlying strata in the outcrops. As indicated on the correlation chart, such sands occur at

1,100-1,200 feet below the base of the McLure shale in Huffman No. 1, and at approximately equivalent positions in wells 61-20-Q and Burbank No. 1 (Middle dome), though in the latter well the top of this zone is less sharply defined.

Orthoclase-anhydrite sand.—At about 100 feet above the andesitic sand zone in the wells there is a thin but distinctive zone in which orthoclase forms 50 per cent or more of the light mineral grains, as compared with the 20 per cent or less that is usual at other horizons. This orthoclase is in large part fresh, and much of it is sanidine, though there is also some altered orthoclase of the ordinary variety and some microcline. Anhydrite occurs as a "flood" in the heavy separate, and perfect rhombs of secondary dolomite are abundant. This sand may represent an alkalic pyroclast zone, though it does not contain any bentonitic clay matrix. It occurs at about the same horizon as the lithologic unit in wells 8-1-P and 41-3-P called the "lower variegated," as indicated on the chart. Farther south, in Burbank No. 1 of the Middle dome, it is apparently not a distinctive sand, to judge from the samples available. If present in the outcrops, it is too poorly developed to be found in the samples collected.

600-foot shale.—The 600-foot shale is mentioned here—though it is not one of the mineral zones—because it is an important lithologic key bed in the wells and includes one of the few recognizable fossil horizons. It occurs, as the name indicates, about 600 feet below the top of the producing sands in the North dome. According to R. M. Kleinpell, this shale contains *Foraminifera* characteristic of the Gould shale of Barbat, which immediately overlies the Temblor in the type region. The sandstones overlying and underlying this shale are not very distinct mineralogically, except that the beds above carry very abundant chromite and in the beds below chromite is distinctly less common. Largely on the basis of this difference in the proportion of chromite, the 600-foot shale was located in some of the wells and was tentatively correlated with the shaly beds at about 7,930-7,970 feet in Burbank No. 1. Owing to the considerable horizontal distance of this well in the Middle dome from other sections, such meager mineralogic basis for this correlation was very unsatisfactory, but subsequent information, kindly supplied by D. D. Hughes and R. M. Kleinpell, indicated that this particular shale in Burbank No. 1 carries the foraminiferal fauna of the Gould shale of Barbat, thus checking the correlation. Neither this lithologic unit nor its fauna has been recognized at the outcrops, as is discussed later.

Big Blue serpentine zone.—The most distinctive and clear-cut mineral zone in the section is the Big Blue serpentine zone, whose most

conspicuous feature is the abundance of serpentine grains, largely of the antigorite variety. Perhaps even more useful in delimiting this zone is the abundant uvarovite, or green garnet, occurring in the heavy separate. This peculiar green garnet is rare or absent elsewhere in the section but in this zone shows more uniformity in quantity than the serpentine, which seems to vary considerably with the texture of the sand and other factors. This type of garnet is mentioned again in connection with some details on the more interesting individual minerals. Glaucophane and titanite are also relatively common in this zone. Some very small arenaceous *Foraminifera* are present in the upper part of the zone and in sands immediately overlying it, but they represent types that would probably prove of little value for stratigraphic determinations. This serpentine zone is encountered about 100 feet below the top of the producing sands in the North dome wells and is about 150 feet thick, extending down nearly to the unit called "upper variegated." Its character in the Middle dome is unknown, but apparently it is not well developed in this area, though no cores were available in Burbank No. 1 at the depths where it might be expected. In the Reef Ridge outcrops this zone is not present, though sample L-22, from Big Tar Canyon, contains small amounts of serpentine and uvarovite and a few serpentinous pebbles, indicating a closely related or equivalent zone. In the section of the Coalinga East-Side field, as discussed below in the part on general stratigraphic relations, this mineral zone is well developed and is called the Big Blue. The serpentine and associated uvarovite are obviously derived from the Franciscan in the hills of Joaquin Ridge, south of New Idria.

The sands about 100 feet thick that form the uppermost part of the sands in the North dome and overlie the serpentine zone consist of a rather uniform mineral assemblage of nondescript character, as indicated in the mineral data sheets of wells 41-3-P and 8-1-P. In the southern part of the North dome these sands become more shaly, and in the Middle dome the beds are largely shale that is lithologically similar to the overlying siliceous McLure shale.

Bentonite key bed.—In the basal part of the McLure shale there are one or more bentonite beds a foot or more in thickness, and the lowest of these beds, occurring about 50-80 feet above the top of the sands in the North dome, is generally used as a marker or key bed in correlations. This bed is used as the datum plane in the accompanying correlation chart. The bed has not always been cored, especially in earlier drilled wells, and its position is not known in wells 8-1-P and 61-20-Q. The bentonite at 7,277 feet in Burbank No. 1 is underlain by a con-

siderably greater thickness of shale resembling the McLure than the bentonite in the North dome wells, but other lines of correlation suggest that the two beds are equivalent. At the outcrops this bentonite occurs about 15 feet above the base of the McLure in Canoas Creek and near Big Tar Canyon.

McLure shale.—The characteristic McLure shale is about 450 feet thick in the Reef Ridge outcrops and is more than twice as thick in the wells of the North dome, with an increasing thickness southward. It is hard siliceous brown shale or mudstone, in which diatom impressions as molds and casts are locally abundant and fish scales are common. The upper limit of this unit is indicated mainly by change in drilling rate, but lithologically is difficult to place, as the change to the superjacent unit is generally gradational.

Caving shale.—The soft, silty shale called "caving shale" is regarded as only 250 feet thick at Big Tar Canyon, though its limits are indefinite, owing to gradational transitions at the base and top. In the outcrops it is rarely well exposed, and the mode of weathering suggests a bentonitic shale.¹⁰ In the wells this unit is a "blue" sandy shale with thin sands, and its drilling character is suggested in the term "caving shale." In the basal part sands become more conspicuous in such wells as 8-1-P and Bolsa Chica Ferguson No. 1, and these sands are very distinct mineralogically. They contain a bentonite matrix or groundmass that shows the characteristic swelling in water, and the sand grains include very abundant andesine phenocrysts, much biotite, spherules of barite, and rhombs of secondary dolomite. Higher in this shale unit the pyroclastic materials have the composition of a hornblende andesite, and this grades up into the succeeding unit.

Andesitic sands of Jacalitos formation.—The Pliocene andesitic sands of the Jacalitos formation contain an abundance of fresh zoned andesine, more or less altered volcanic glass, and ferromagnesian minerals. In the lower part the ferromagnesian mineral is largely hornblende, but in the upper half augite becomes increasingly abundant. A large part of this sand is pyroclastic, though admixed with much ordinary clastic sand. Most of the original vitric or glassy tuff has been altered to minute zeolitic crystals that appear to be clinoptilolite.¹¹

¹⁰ This shale has recently been termed the "Reef Ridge shale" by Barbat and Johnson. (See G. C. Gester and John Galloway, "Geology of Kettleman Hills Oil Field, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 10 (October, 1933), pp. 1174-76.

¹¹ M. N. Bramlette and E. Posnjak, "Zeolitic Alteration of Pyroclastics," *Amer. Mineralogist*, Vol. 18, No. 4 (1933), pp. 167-71.

Andesitic sands of Etchegoin formation. The andesitic sands of the Etchegoin formation are also in considerable part pyroclastic admixed with ordinary clastic material and contain the same andesitic phenocryst minerals and altered vitric material as the Jacalitos. However, there is also a large amount of hypersthene, and all the beds that are called "blue sands" contain abundant hypersthene. The heavy mineral content of these Pliocene sands is unusually high, commonly forming 20 per cent or more of the total. No mineral data on the Pliocene formations are presented here, as they are not much involved in the subsurface correlations considered in this paper.

CORRELATIONS AND GENERAL STRATIGRAPHIC RELATIONS

The lack of any horizontal scale in the correlation sheet results in a distorted picture of the lateral variations in stratigraphic units, particularly the larger variations that occur between the outcrops along Reef Ridge and the wells of the field.

The relative position of all available core samples examined is indicated by the small dashes at the left of the well sections, and a similar convention is used for the samples from the outcrop sections. Depth figures are given for the cores only at a few critical positions. As will be noted, there are some large intervals in the various wells for which no samples are available and the correlation lines must be extended with question marks, as for the andesitic sand zone in well 41-3-P. The approximate position of the andesitic sand zone in this well is indicated by the correlation of the distinctive orthoclase-anhydrite sand zone with adjacent wells.

No correction of intervals for dip is made in this correlation chart, as most of the wells are near the crest of the anticline, where the dip is low, and the core depths and mineral zones can thus be shown with positions as recorded in the well logs. The Blauvelt well No. 1 (1-36-J), however, is far down on the east flank, and the uncorrected steep dip results in a considerable distortion of the correlation lines. The McLure shale thus appears much thicker than it really is, and there is a corresponding warping of the lines in the sands below the datum plane.

The correlations of the heavy minerals support the view that the Bolsa Chica Ferguson No. 1, which is down on the west flank of the anticline, has penetrated only into the bentonitic sand of the basal caving shale at the total depth of 7,694 feet, and only the lowest part of this well section is represented on the chart. This interpretation is further supported by the results of a study of *Foraminifera* from the lower part of this well made for the United States Geological Survey by R. M. Kleinpell.

The distinctive serpentine zone, with the characteristic mineral content of abundant serpentine and uvarovite grains, is correlated with the Big Blue serpentinous member that is conspicuous in the outcrops northward from the Coalinga anticline along Monocline Ridge and shows a similar mineral composition. The relations in the outcrops along Reef Ridge suggest that this zone is absent there through a disconformity between the McLure shale and the sandstone referred to the Temblor, and that the disconformity is nondepositional rather than erosional. However, in Big Tar Canyon the uppermost sand sample (L-22) below the bentonite contains a small amount of serpentine and uvarovite and thus suggests a thin zone related, if not equivalent, to the Big Blue.

The mineral data suggest some interesting stratigraphic relations at this horizon immediately above the andesitic sand zone at the outcrops. As indicated in the mineral data sheets and correlation chart, this uppermost 60 feet of sand (below the key bentonite) in Big Tar Canyon is distinct from the underlying andesitic sands. It has a rather nondescript mineral assemblage, but in containing very abundant chromite it resembles the sands overlying the 600-foot shale in the wells, whereas the sands in a corresponding position on Canoas Creek contain a much smaller proportion of chromite, like the sands below the 600-foot shale in the wells. This very meager evidence affords a suggestion that disconformity due to nondeposition occurs at different stratigraphic positions in these two sections, and it is interesting to note that *Scutella merriami* is found in these upper sands on Canoas Creek and not in Big Tar Canyon. A single sample (C-2A) from Canoas Creek, taken from a thin conglomerate in the shaly beds between *Scutella*-bearing beds and the bentonite, contains abundant chromite and a little uvarovite and thus resembles the uppermost 60 feet of Big Tar Canyon. Some of the pebbles of this thin conglomerate are composed of serpentine. Though the mineral evidence at this horizon is not distinct enough to be more than suggestive, there is a possibility that the upper 60 feet of Big Tar Canyon may be equivalent to sands overlying the 600-foot shale in North Dome, and that the sands at a corresponding position on Canoas Creek are older sands beneath the horizon of the 600-foot shale. Collections of fossils from the upper 60 feet of Big Tar Canyon have not yet been studied, but according to field determinations by W. P. Woodring, this part of the sandstone contains *Clementia pertenuis* and *Miltha sanctaerucis*, neither of which is found in the underlying andesitic sand. On the Coalinga anticline *Clementia pertenuis* occurs in the uppermost part of the sandstone referred to the Temblor in the beds containing

Arnold's "unique fauna"¹² but not in the underlying *Scutella*-bearing sandstone.

All the sands above the 600-foot shale in the Kettleman Hills wells would appear from the mineral data to be different and stratigraphically higher than the andesitic sand zone that composes most of the Temblor of the outcrops in Reef Ridge. The 600-foot shale contains a foraminiferal fauna similar to that of the Gould shale of Barbat which immediately overlies the type Temblor.

Such a correlation indicates a marked difference in the succession and thickness of stratigraphic units between the wells and the outcrops in Reef Ridge, and it supports the view that the upper part of the producing sands is younger than the type Temblor.

Petrographic examination of some samples collected from the section on the Coalinga anticline, including samples from the top of the Kreyenhagen up into the Pliocene, indicates that the sands here show a marked difference in mineral content from those of the area under discussion. In the fossiliferous Temblor of this northern area, including the *Scutella*-bearing beds, there is an abundance of hypersthene, which is very rare or absent in equivalent strata farther south, and also some andalusite and kyanite, which are not present in the southern area. The beds above the Temblor also show differences that preclude any satisfactory correlation on the basis of mineralogy, except for the very distinctive strata of the Big Blue serpentinous member. With the aid of this zone, it would perhaps be possible to carry through the mineralogic correlations and understand these lateral changes in stratigraphy toward the north, if intermediate sections, such as those in the wells of the Guijarral Hills and the Jacalitos dome, were studied. Such a study might give additional data on the relations of the Santa Margarita sands of the Coalinga region and the McLure shale of the Kettleman region.

NOTES ON SOME INDIVIDUAL MINERALS

Pyroclasts.—The shards of volcanic glass occurring in the andesitic sand zone of the Temblor are more or less altered, with a resulting decrease in their index of refraction, and in part have gone over to a clay mineral. The bentonite beds in the basal McLure shale represent purer beds of originally vitric pyroclasts and are largely altered to a bentonitic clay mineral, but some of the larger relict shards are altered to the mineral clinoptilolite. The bentonitic sands in the basal part of the caving shale show the vitric material largely altered to a bentonitic clay groundmass with sand-size phenocrysts composed

¹² U. S. Geol. Survey Bull. 398 (1910), p. 87.

largely of andesine, biotite, magnetite, et cetera. The vitric pyroclasts in the Jacalitos are largely altered to the zeolitic mineral, and in the Etchegoin a similar alteration is usual, but many of the shards are apparently fresh and isotropic.

Just what factors determine the degree and kind of alteration of the vitric pyroclasts is not evident, as original composition seems to be only one factor, and possibly not the most important. Most of the glass material, where apparently fresh, shows an index of refraction of $1.50 \pm$, whether the associated phenocrysts are rhyolitic (quartz and sanidine) or andesitic (andesine and ferromagnesians). However, the pyroclastic materials in the basal part of the McLure shale show a more complete alteration to bentonitic clay, and with this are associated phenocrysts of rhyolitic or alkalic types. There is some suggestion of a possible relation of the alteration to depth in the stratigraphic section.

Blue sands.—In the Etchegoin tuffaceous sandstones of the Pliocene the so-called "blue sands" are very common. The blue color is due to a very thin film of a soft mineral encrusting the sand grains. Various tests indicate that this mineral is neither vivianite nor opal, two minerals that have been previously suggested.¹³ The thin film is difficult to study optically, but appears to be some secondary mineral of chloritic type. Its formation seems in some way connected with the presence of hypersthene, as it was found that the hypersthene was consistently present in large amounts in the blue sands but not abundant in the interbedded sands that do not show the blue color.

Other minerals.—Barite is common throughout most of the section studied in the core samples from wells, though not found commonly in the outcrop samples of this area. It seems generally to be a secondary or authigenic mineral, and perhaps its formation is related to the water circulation in the sands, as its absence in most of the outcrop samples could hardly be due to a surface leaching of a mineral that is comparatively insoluble. The ultimate source of the barium is probably the feldspars and micas, and it is known that the igneous rocks of the Rocky Mountain and Pacific regions contain more barium than the average.

Among the heavy minerals of the serpentine zone a peculiar type of garnet is very abundant. This isotropic mineral occurs as irregular or "ragged" grains of very pale to deep green color, and much of it has a leached or altered appearance, with only scattered grains show-

¹³ Robert Anderson and R. W. Pack, "Geology and Oil Resources of the West Border of the San Joaquin Valley, North of Coalinga, California," *U. S. Geol. Survey Bull. 603* (1915), pp. 82-83.

ing crystal form. The few with good crystal form show dodecahedral faces, and it was for this reason that the mineral was classed as the green garnet, uvarovite, rather than a green spinel. A large piece of serpentine boulder from the Big Blue outcrops, sent to the writer by Max Krueger, shows a thin seam of this same mineral. Such a mode of occurrence of a green chrome garnet, as thin fracture fillings, is not rare in the Franciscan serpentine rocks of California, from which the Big Blue was obviously derived.

Titanite is one of the very common heavy minerals, though it is absent at certain horizons. The relations of anatase to titanite strongly suggest that the anatase, which occurs as secondary or authigenic crystals, was formed from the titanite. The mineral data sheets show that at the horizons where this secondary anatase is abundant there is little or no titanite, and *vice versa*. In the samples where both of these minerals are rather common, the titanite grains have a ragged or etched appearance, as if strongly corroded. Brookite is generally present, but is rare in all samples and is less obviously authigenic. The writer has noted abundant authigenic crystals of brookite, rather than anatase, in other regions, and this brookite seemed probably derived from ilmenite. Secondary titanite has also been observed, but less commonly, and that present in the sediments here studied is not secondary. The conditions that determine which of these titanium minerals will form secondarily in sediments are not clear, but an interesting discussion on the subject was written as early as 1892.¹⁴

The hornblende and hypersthene in part show cockscomb terminations that are probably the result of etching or corrosion, and the augite more generally shows this condition.

The staurolite in the lower part of the Miocene section is generally of a pale yellow color and exhibits more or less distinct corrosion, much of it showing mere skeleton forms with cockscomb terminations, whereas the staurolite in the Pliocene is a deeper yellow and not corroded. A similar change in the staurolite with relation to the older sediments in the section has been observed in other regions and therefore suggests a relative instability of this mineral under certain conditions.

Some of the garnet shows a certain degree of etching. In some other regions the garnets are strongly etched to mere skeleton crystals, though this would seem to be connected with some special environment, as garnet is generally stable. The evidence for the instability of

¹⁴ W. M. Hutchings, "Notes on the Ash-Slates and Other Rocks of the Lake District," *Geol. Mag.*, Vol. 9 (Dec. 3, 1892), p. 221.

some of these minerals, and additional data cited by Boswell,¹⁵ suggest that the paucity and uniformity of the suites of stable minerals in many of the older Paleozoic formations may be largely a result of this instability under varying environments within the strata, rather than altogether an evidence of reworking and derivation from pre-existing sediments.

Among the rarer minerals that were not tabulated in the mineral data sheets, because their sporadic occurrence made them difficult to consider and they are probably of little significance in correlation, are monazite, crossite, and lawsonite. A very rare grain of vesuvianite and piedmontite was identified.

A few minerals, particularly in the light fraction, offer difficulties in making a close estimate of their relative abundance without an undue amount of work. The sodic plagioclase is one of these, and the proportion shown in the accompanying data is probably subject to considerable error, as some of the grains not showing any plagioclase twinning have doubtless been included with the orthoclase. The chert grains are probably fewer than is indicated in the data, because some other finely crystalline aggregates of similar refringence may have been classed with the chert. Under "rock grains" are included a variety of aggregate grains that are in part merely undisintegrated particles, but in the andesitic sand zone these consist largely of finely crystalline andesitic rock. Among the heavy minerals no attempt was made to differentiate the magnetite, ilmenite, and other opaque minerals; a rather arbitrary distinction was used in the differentiation of epidote and zoisite, and some clinzoisite was included with the zoisite.

No attempt was made to note varietal characteristics within mineral species, though such fine discrimination would doubtless give additional information. The limit to be placed on such work as is here recorded is merely a compromise, the aim being to obtain a maximum of pertinent data in the time that may be available.

¹⁵ P. G. H. Boswell, *On the Mineralogy of Sedimentary Rocks* (1933), pp. 37-46.

PERMIAN LEDGE-MAKERS IN CONCHO COUNTY, TEXAS¹

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ABSTRACT

This paper describes the Permian rocks exposed in Concho County, Texas, with especial reference to the ledge-making members. All the Lower Permian Wichita group and the lower part of the overlying Clear Fork formation are exposed in the county. Names are proposed for three persistent ledge-making members.

INTRODUCTION

Concho County is in central Texas. The southern part of the county is covered by Lower Cretaceous (Comanche) rocks, but the Wichita³ group of Lower Permian formations and the lower part of the overlying Clear Fork⁴ formation (or group) are exposed in the northern part of the county. These Permian strata have a westerly inclination of about 50 feet to the mile so that about 1,600 feet of section are exposed.

As the southernmost exposures of these Permian rocks are in Concho County, a study of their section there is of particular interest. In the stratigraphic section (Fig. 2) the unmarked intervals between the ledge-makers are occupied by shale and some limestone strata. The accompanying map (Fig. 1) shows the areal geology of the county.

A. J. Montgomery traced beds in the Clear Fork, Lueders, and Paint Rock formations in the west-central part of the county. The remainder of the tracing was done by the writer. As the ledge-makers were traced with plane-table surveys, computations of intervals and correlations across local areas of poor exposures are based on accurate altitude and location data.

GROUPS OF STRATA

The oldest strata exposed in Concho County are in the upper

¹ Published by permission of the Phillips Petroleum Company, Bartlesville, Oklahoma. Manuscript received, April, 1934.

² 606 Eleventh Street.

³ N. H. Darton, L. W. Stephenson, and Julia Gardner, "Geologic Map of Texas" (preliminary edition), *U. S. Geol. Survey* (1932).

⁴ *Ibid.*

part of the Putnam formation. These strata, with the Coleman Junction limestone member at their top, crop out in the eastern part of the county. The Putnam is the topmost formation of the Cisco⁵ group of Upper Pennsylvanian and Lower Permian formations.

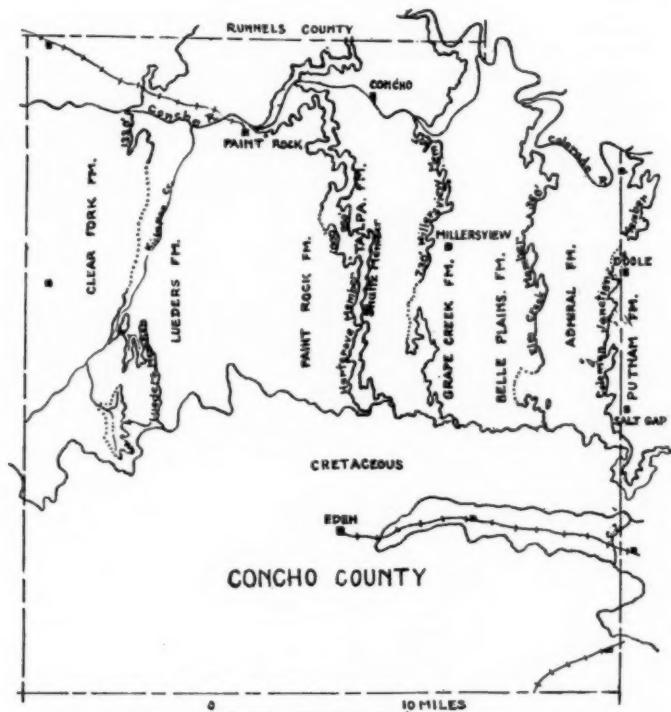


FIG. 1.—Areal geologic map of Concho County, Texas, showing stratigraphic distances of prominent ledge-makers above Coleman Junction limestone member.

All the Wichita group of Lower Permian formations is exposed in the county. This group includes all the strata above the Coleman Junction to the top of the Lueders limestone member. Named from younger to older with their thicknesses in Concho County, the formations of the group are given on page 1580.

⁵ *Ibid.*

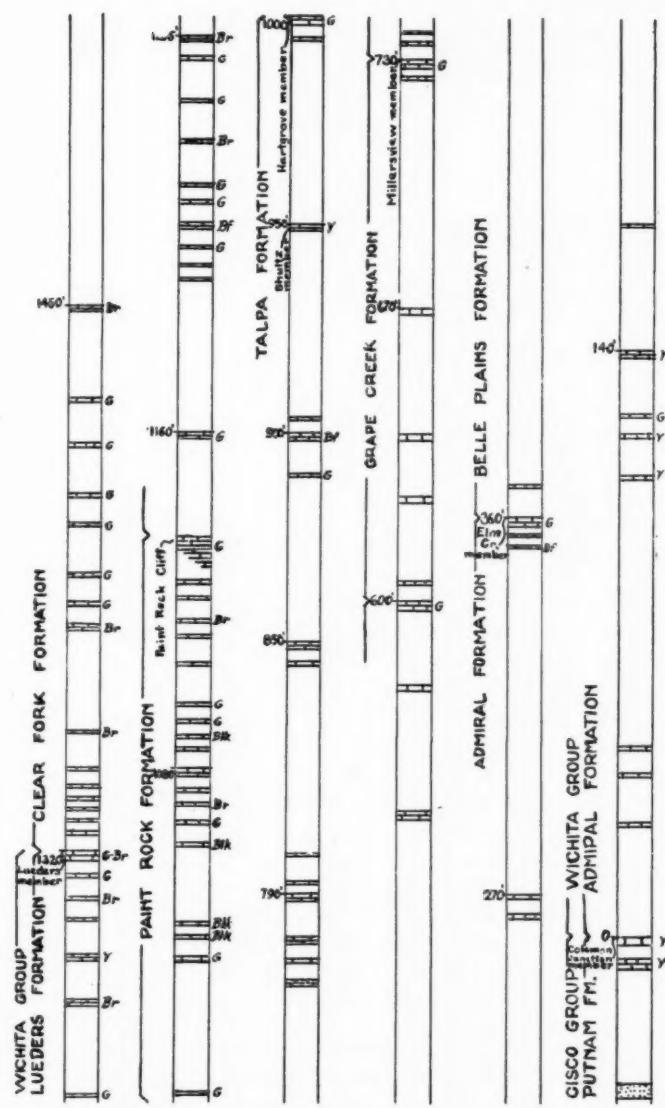


FIG. 2.—Section of Permian rocks in Concho County, Texas, showing stratigraphic distances above Coleman Junction limestone member. Scale: 1 inch equals 40 feet.
Blk, black; Br, brown; Bf, buff; G, gray; Y, yellow.

WICHITA FORMATIONS

	Feet
Lueders* formation.....	185
Paint Rock† formation.....	135
Clyde‡ formation [Talpa‡ formation.....	270
Grape Creek§ formation.....	130
Belle Plains¶ formation.....	240
Admiral** formation.....	360
	1,320

* J. W. Beede and V. V. Waite, "The Geology of Runnels County," *Univ. Texas Bull.* 1816 (March 15, 1918), pp. 41-45.

† *Ibid.*, pp. 56-42.

‡ *Ibid.*, pp. 30-36.

§ *Ibid.*, pp. 21-30.

¶ F. B. Plummer and R. C. Moore, "Stratigraphy of the Pennsylvanian Formations of North-Central Texas," *Univ. Texas Bull.* 2132 (June 5, 1921), pp. 197-98.

** *Ibid.*, pp. 195-97.

¶ *Ibid.*, pp. 192-94.

Only the lower part of the Clear Fork formation, formerly considered as a series* or group of Middle Permian formations, is exposed in the western part of the county.

CISCO GROUP

PUTNAM FORMATION

The Coleman Junction limestone member is the only persistent ledge-maker in the Putnam formation in Concho County. This member is composed of two yellow limestone beds having an interval of 5 feet from top to top. Convenient places of reference are (1) on the road (NE. $\frac{1}{4}$, E. $\frac{1}{2}$ Curtis Morris Survey No. 742) 0.4 miles west of the school at Doole and (2) on the road (SW. cor. James F. Irwin Survey No. 1684) 1 mile west of Salt Gap.

A 4-foot bed of sandstone which is 35 feet below the top of the Coleman Junction crops out (NE. $\frac{1}{4}$, E. $\frac{1}{2}$ Curtis Morris Survey No. 742) on the road 0.3 mile west of the school at Doole.

WICHITA GROUP

ADMIRAL FORMATION

A cherty yellow limestone bed which is 140 feet above the Coleman Junction makes a ledge for several miles north of the Cretaceous escarpment. It may be visited conveniently (1) on the road (NE. $\frac{1}{4}$, NE. $\frac{1}{4}$ H. F. Fisher and B. Miller Survey No. 2731) 2.1 miles west of the school at Doole, and (2) on the road (NE. cor., NW. $\frac{1}{4}$ J. B. Wallace Survey No. 10) 2.5 miles west of Salt Gap.

The Elm Creek limestone, the top member of the Admiral formation, is 360 feet above the Coleman Junction. It is composed of 2 feet of gray limestone. This member may be visited (1) (NE. cor. H. & T.

* "The Geology of Runnels County," *op. cit.*, pp. 46-49.

C. R. R. Co. Survey No. 59) on the road that traverses from Salt Gap: 3 miles west; thence 1 mile north; thence 2 miles west to the outcrop, and (2) (N. $\frac{1}{2}$ H. & T.C. R. R. Co. Survey No. 39) just south of the road 4.3 miles west of the school at Doole and on the road 0.4 mile farther west.

BELLE PLAINS FORMATION

There are no persistent ledge-makers in the Belle Plains formation in Concho County, though a limestone bed which is 600 feet above the Coleman Junction and which is considered as being the top member of the formation forms a short escarpment near the Cretaceous area. This bed makes a good ledge in W. $\frac{1}{2}$ Alexander Gregg Survey No. 78, near H. Adams's Price well No. 1, 7 miles south of Millersview.

GRAPE CREEK FORMATION

A 1-foot bed of dark gray limestone which is 670 feet above the Coleman Junction makes a ledge between Millersview and Concho River. This bed might be called the Winkler Ford member, for it crops out (0.1 mile south of NW. cor. Elizabeth Aurand Survey No. 1861) on the road 1.2 miles southeast of that crossing on Concho River.

The Millersview⁷ limestone member is a 2-foot gray bed which is 730 feet above the Coleman Junction. It crops out (in W. $\frac{1}{2}$ T. F. Benge Survey No. 100) 4.5 miles south-southwest of Millersview on the road having that bearing from the village. This member may also be visited conveniently (near the center of Heinrich Eimke Survey No. 7) at its outcrop on the road 0.3 mile east of the Currie School, which is situated between Concho and Colorado rivers, 3.5 miles southwest of their junction. The Millersview has been traced across southeastern Runnels County to a point 4.5 miles north of the southeast corner of that county. As the Millersview is a persistent ledge-maker having the requisite stratigraphic position and geographic location of outcrop in Runnels County, it is here considered as being the top member of the Grape Creek formation.

TALPA FORMATION

Several limestone members of the Talpa formation make rather persistent ledges. A 1-foot gray bed which is 790 feet above the Coleman Junction makes a ledge between Concho and Colorado rivers, and forms a peninsula-like outcrop which comes to a point (near the

⁷ Name available according to the records of the Committee on Geologic Names, U. S. Geological Survey.

center of N. $\frac{1}{2}$ Heinrich Eimke Survey No. 8) in the pasture 0.2 mile northwest of the Currie School. Another 1-foot gray bed which is 850 feet above the Coleman Junction crops out (0.9 mile south of NW. cor. Peter Horne Survey No. 20) on the road 0.4 mile north of the school that is in the village of Concho. A 1-foot buff bed which is 900 feet above the Coleman Junction crops out (0.3 mile west of SE. cor. T. & N. O. R. R. Co. Survey No. 129) on the road 0.3 mile west of the Duck Creek School, which is 7 miles southeast of Paint Rock.

The uppermost 50 feet of the Talpa formation contain two persistent ledge-makers. The lower of these two members is a 2-foot bed of yellow limestone which is 950 feet above the Coleman Junction. This bed is here called the Shultz⁸ member from the ranch house of Mrs. Winifred Shultz, which is situated on the peninsula-shaped ledge formed by the outcrop (in NE. $\frac{1}{4}$ T. & N. O. R. R. Co. Survey No. 127) 8 miles southeast of Paint Rock. This member may be conveniently visited 1.8 miles northwest of Concho (near the middle of the west line of Bernard Heiss Survey No. 23) where it crops out just west of the north-south road. A 2-foot dark gray limestone bed which is 1,000 feet above the Coleman Junction is here called the Hartgrove⁹ member from its exposure on Mack Hartgrove's ranch where it crops out 0.4 mile south of and 37 feet lower than the ground at the Eugene Mays well (middle of the west line of Anton Schmidz Survey No. 312, about 4.5 miles southeast of Paint Rock). The Hartgrove member may be visited 4 miles northeast of Paint Rock where it crops out (near SW. cor. Johannes Arnold Survey No. 35) on the road along the north side of Concho River 2.8 miles east of the north-south highway. The Shultz and Hartgrove members have been traced across southeastern Runnels County to points 9.3 miles and 11 miles respectively north of the southeast corner of that county. Because the Hartgrove member is a persistent ledge-maker having the requisite stratigraphic and geographic positions, it is here considered as being the top member of the Talpa formation.

PAINT ROCK FORMATION

None of the limestone members of the Paint Rock formation makes a persistent ledge, although many of them were traced for short distances. The gray limestone beds in the painted cliff (near the south lines of Edward Grobe surveys No. 47 and No. 48) on the north side of Concho River 1 mile northwest of Paint Rock are considered as the

⁸ *Ibid.*

⁹ *Ibid.*

top member of the Paint Rock formation. This member does not make a persistent ledge.

LUEDERS FORMATION

Although many of the limestone beds in the Lueders formation were traced for short distances, only two of them make persistent ledges. A 1-foot gray bed which is 1,255 feet above the Coleman Junction crops out at the Noble Oil Company's Simms well No. 1 (center, S. $\frac{1}{2}$ J. J. McHenry Survey No. 12, about 5 miles north-northwest of Paint Rock), and makes a ledge for several miles. The Lueders limestone member, at the top of the formation, is 1,320 feet above the Coleman Junction. The Lueders member may be visited 5 miles west-northwest of Paint Rock, where its outcrop crosses the railroad (near the center of Andreas Helmke Survey No. 65) 3.3 miles west of the Simms Valley siding. Near the Cretaceous escarpment this member may be visited at its outcrop on the road 0.3 mile north of and 0.2 mile east of the NW. cor. Sec. 3, Blk. 9, H. & T. C. R. R. Co. Survey.

CLEAR FORK FORMATION

The limestone beds in the lower part of the Clear Fork formation do not make persistent ledges, though several of them were traced short distances in the area near the Cretaceous escarpment.

MECHANICS OF LOW-ANGLE OVERTHRUST FAULTING
AS ILLUSTRATED BY CUMBERLAND THRUST BLOCK,
VIRGINIA, KENTUCKY, AND TENNESSEE¹

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ABSTRACT

The structural relations of the Cumberland overthrust block are such as would occur if gliding on the thrust plane took place parallel with the bedding along certain shale beds in such a way that the thrust plane followed a lower shale bed for some distance, then sheared diagonally up across the intervening beds to a higher shale, followed that for several miles, and again sheared across the bedding to the surface.

Reasons are given for the belief that subsidiary faults and folds within the block are superficial and do not extend below the thrust plane. This possibility should be borne in mind when exploration of such structures for oil or gas is contemplated.

Study of the Cumberland block throws new light on the broader problems of the nature of folding and faulting in the sedimentary rocks bordering great mountain ranges and on the function of friction in setting limits to the distance through which overthrust blocks can be moved.

INTRODUCTION

It is now generally recognized that low-angle overthrust faults are common and that the movement on some of them has amounted to several miles, but in most cases the manner in which such thrusts are produced, the limits of movement set by friction, and the function of the nature and attitude of the rocks in guiding and controlling the faulting have not been clearly understood.

A clue to the solution of one such problem has been revealed by a study of the Cumberland fault block, a rectangular overthrust mass about 125 miles long and 25-30 miles wide, located at the common corners of the states of Virginia, Kentucky, and Tennessee. This area, which marks the outer limit of the Appalachian overthrusting in that district, shows the essential mechanics of the thrust faulting because the process has not been carried far enough to obscure the record.

CUMBERLAND FAULT BLOCK

The Cumberland overthrust block has been described in consider-

¹ Presented before the Association at the Houston meeting, March 24, 1933.
Manuscript received, May 4, 1934.

² Department of geology, University of Cincinnati.

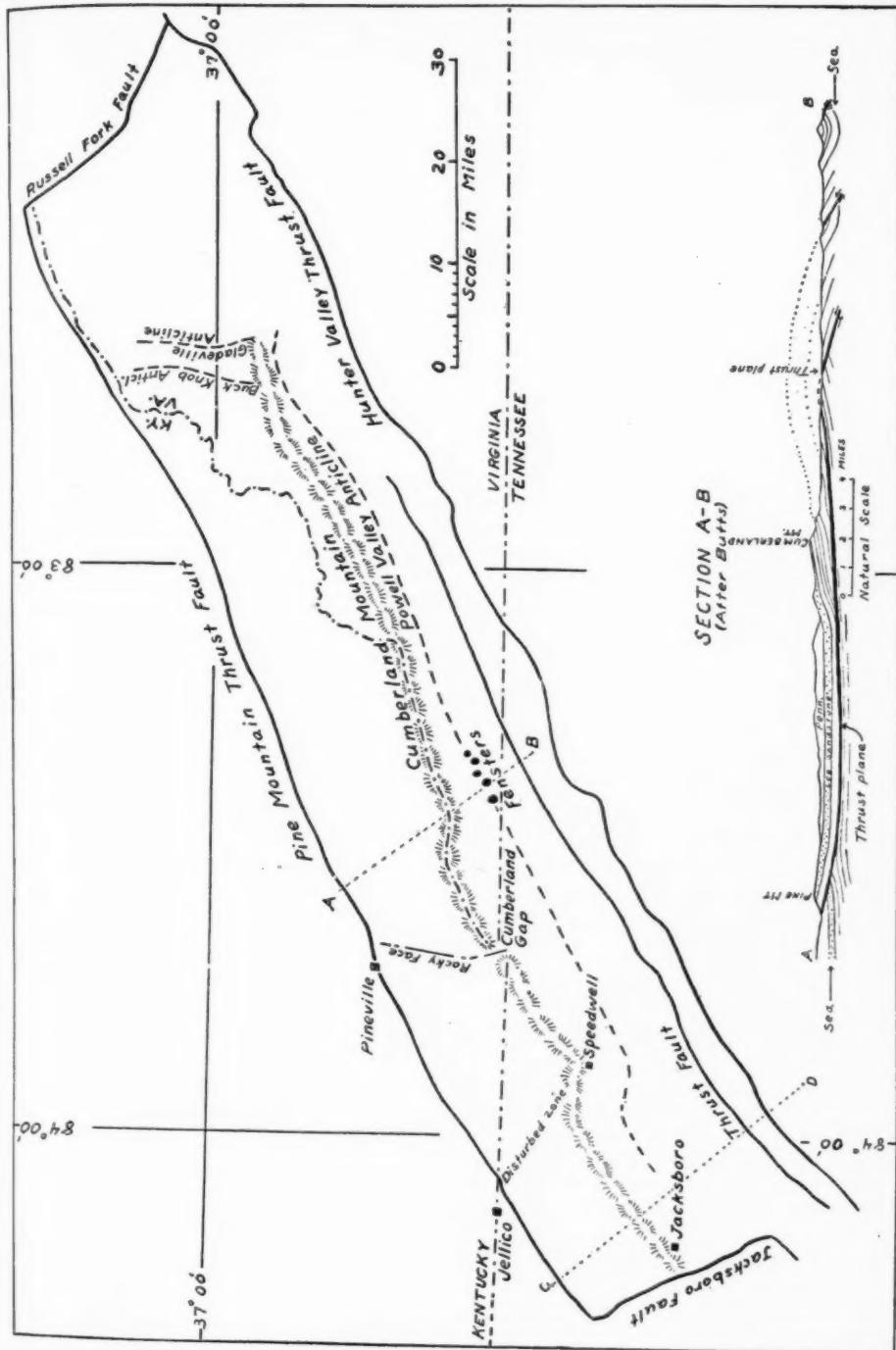


FIG. 1.—Cumberland overthrust block.

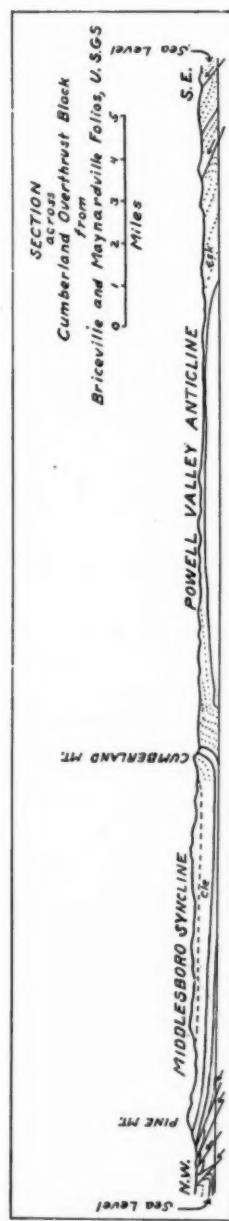


FIG. 2.—Topographic and geologic cross section of western part of Cumberland overthrust block along line CD (Fig. 1), showing flat-topped Powell Valley anticline and flat-bottomed Middleboro syncline; also showing earlier, now disproved, conception of relations of Pine Mountain thrust fault. From Briceville and Maynardville folios, United States Geological Survey.

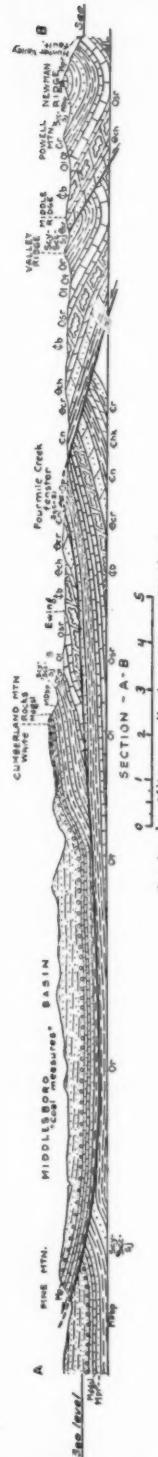


FIG. 3.—Cross section of Cumberland overthrust block showing fensters and newer conception of relations of Pine Mountain fault. Courtesy of Charles Butts and Virginia Geological Survey.

able detail by Wentworth,³ and certain of its features in still more detail by Butts.⁴

The block (Fig. 1) is bounded on the northwest by the Pine Mountain thrust fault; on the southwest by the Jacksboro tear fault, upthrown toward the southwest; on the northeast by the Russell Fork tear fault, along which there has been some overthrusting, but not so much as on the Jacksboro fault; and on the southeast by the Hunter Valley thrust fault. The latter fault plays no part in the mechanics of the block—it merely marks it off from other fault blocks farther southeast.

STRUCTURE WITHIN BLOCK

The structure within the Cumberland block is illustrated by the two accompanying cross sections (Fig. 2 and Fig. 3). Figure 2 is taken from the Briceville folio (No. 33) of the United States Geological Survey, and Figure 3, from Butts' paper referred to in the foregoing paragraphs.

From these two sections it is apparent that the Cumberland block is divided lengthwise into two major units—a broad, flat-bottomed syncline called the Middlesboro syncline or Middlesboro basin, and a broad, flat-topped anticline, called the Powell Valley anticline—separated by the sharp Cumberland Mountain monocline.

The topographic features of the block are expressions of these structures and of the varying resistances of the rocks brought to the surface by them. Pine Mountain and Cumberland Mountain are monoclinal ridges formed by the outcrop of the resistant basal sandstone (part of the Lee formation) of the Pennsylvanian system. The Middlesboro synclinal basin between them is topographically expressed as a mountainous region of maturely dissected Pennsylvanian rocks and the Powell Valley anticline is expressed as an anticlinal lowland—part of the Great Valley of Tennessee—developed on the relatively non-resistant Ordovician limestones.

The Cumberland block is broken crosswise by three lines of disturbance (Fig. 1), trending roughly parallel with one or another of the tear faults at its ends and therefore bearing essentially shearing-angle relations to the outlines of the block as a whole. The significance of these cross-disturbances is discussed on a following page. Other structural disturbances within the block include at least two strike

³ Chester K. Wentworth, "Russell Fork Fault of Southern Virginia," *Jour. Geol.*, Vol. 29 (1921), pp. 351-69.

⁴ Charles Butts, "Fensters in the Cumberland Overthrust Block in Southwestern Virginia," *Virginia Geol. Survey Bull.* 28 (1927), pp. 1-12.

faults near the top of the Cumberland Mountain monocline. One is on Brush Mountain about 7 miles northeast of Cumberland Gap,⁵ and the other detaches Powell Mountain from Cumberland Mountain about 3 miles southwest of Cumberland Gap. No reference to the last-mentioned fault has been found, and it was not examined in detail in the field, so it is not known whether it is a normal or a thrust fault. These strike faults may have significance as adjustment phenomena—tensional or otherwise—to the movements which accompanied the overthrusting of the Cumberland block.

INTERPRETATION OF STRUCTURE

The older interpretation of the structure of the Cumberland block is indicated by the cross section (Fig. 2) taken from the Briceville and Maynardville folios. That interpretation shows a thrust fault extending indefinitely downward from the base of Pine Mountain. It presents a difficult problem as to the mechanics of the structure for it offers no explanation of the sharp Cumberland monocline or of the flatness of the Powell Valley anticline.

The interpretation of the structure of the block was fundamentally changed by the discovery of several fensters, or "windows," on the Powell Valley anticline⁶ which revealed the fact that beneath the relatively flat-lying Ordovician rocks of the Powell Valley anticline is a thrust plane, below which Silurian rocks are exposed. Later drilling in these fensters proved the presence of the normal Ordovician section below the Silurian.

Butts interpreted the presence of the Silurian rocks beneath the Ordovician at the fensters as indicating that the thrust plane revealed in the fensters must be the same as that which crops out at the base of Pine Mountain and that the thrust plane must, therefore, underlie the whole of the Cumberland block at shallow depth (Fig. 3). Butts suggested that the thrust may have followed the Chattanooga shale, on or within which gliding would have been relatively easy. He estimates that the forward movement on the thrust at this point has been about 7 miles.

Butts' interpretation is believed to be correct and is accepted as a basis for the discussion which follows.

If, in accordance with conventional ideas, the thrust plane is thought of as originally a plane surface, it would have required considerable warping since the thrusting occurred to have produced its

⁵ G. H. Ashley and L. C. Glenn, "Geology and Mineral Resources of the Cumberland Gap Coal Field, Kentucky," *U. S. Geol. Survey Prof. Paper 49* (1906).

⁶ Charles Butts, *op. cit.*

present attitude, with the northerly dip into the Middlesboro syncline. In addition to the pronounced apparent warping of the thrust plane shown on Butts' cross section (Fig. 3), an interesting and significant feature is the fact that in the area between the fensters and Cumberland Mountain, the strata dip northward into the thrust plane. This feature finds a ready explanation in, and is a necessary consequence of, the mechanics of thrusting outlined in the following section. Besides, the explanation to be proposed accounts for the present attitude and northward dip of the thrust plane, as shown in Figure 3, without the necessity of any warping of the thrust plane since it was formed.

EXPLANATION OF CUMBERLAND THRUST

The peculiar structural features of the Cumberland block, namely, the flat-topped Powell Valley anticline, the sharp monoclinal structure at Cumberland Mountain, the flat-bottomed Middlesboro syncline between Cumberland Mountain and Pine Mountain, and the

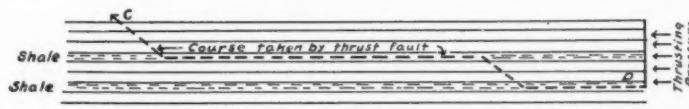


FIG. 4.—Diagram representing course of incipient thrust plane in series of sedimentary rocks. Plane follows beds of easy gliding, such as shales, and breaks diagonally across more brittle beds from one shale to another, and, finally, up to surface.

apparent warping of the thrust plane, all fit into a consistent picture when the thrusting is considered as having taken place along and across the bedding of the sedimentary rocks along some such path

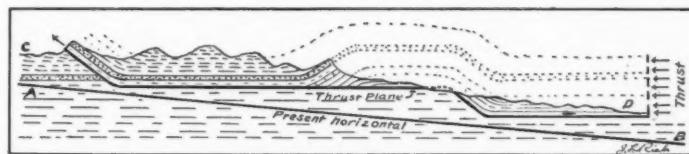


FIG. 5.—Diagram showing result of movement on thrust plane such as that shown in Figure 4. Tilting so that horizontal is represented by line AB and erosion down to line CD gives structure and topography to be compared with present cross section of Cumberland block (Fig. 3).

as that represented by the dotted line, CD , of Figure 4, and the whole region as having been subsequently tilted slightly toward the north.

The thrust plane may be pictured as following some zone of easy

gliding such as the lower shale of Figure 4 until frictional resistance became too great; then shearing diagonally up across the bedding to another shale; following that for several miles, and finally shearing across the bedding to the surface.

Movement along such a thrust plane would inevitably produce almost an exact counterpart of the present structure of the Cumberland block, as may be seen by comparing the actual cross section (Fig. 3) with the diagram (Fig. 5)⁷ and the model (Fig. 6). The model was made by piling sheets of thin paper into a form like that of Figure 4, with a sheet of paper inserted along the course of the potential thrust plane, and then pushing the paper from one side while the other was held rigid. To reproduce, almost exactly, from the diagram or model, the present structure of the Cumberland block, it is only necessary to tilt the diagram or model so that a horizontal line corresponds with the line *AB* of Figure 5 and then to erode the surface down to a line such as *CD*. The fensters then appear along the line where the thrust plane passes into the upper gliding bed after having broken across the bedding from the one below.

Examination of the diagram (Fig. 5), and the photograph of the model (Fig. 6) shows that whether a broad, flat-topped anticline or a narrow one with a rounded crest is formed where the thrust breaks

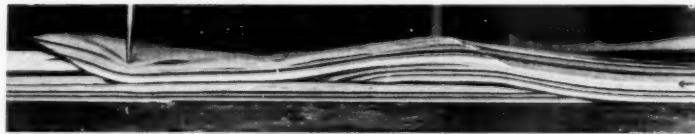


FIG. 6.—Model made by piling paper sheets as in Figure 4 and thrusting toward left.
Note similarity to structure of Cumberland block.

upward from the lower gliding plane depends on the amount of thrusting after the break occurs. If the forward movement is slight, a narrow anticline is formed, whereas greater movement produces a broad, flat-topped anticline.⁸

The Powell Valley anticline seems to illustrate both conditions in different parts of its course. At the west end it is broad and flat-

⁷ The diagrams, Figures 4 and 5, indicate the thrust pressure as applied entirely at one end. Without going further into the matter, attention is called to the fact that this representation is only diagrammatic, and that it seems possible, and certain features make it seem even probable, that the actual force which caused the slipping on the thrust plane was applied from above as well as from the side through the medium of an overthrust sheet now removed by erosion.

⁸ This relation is easily seen by constructing a model like that shown in Figure 6 and varying the amount of thrust.

topped; toward the east it gradually narrows and assumes a rounded crest; and ends abruptly before the end of the block is reached. In accordance with the proposed interpretation, this condition indicates that at the west end, where the thrust broke across from the lower to the upper gliding bed, the strata were pushed forward for several miles; at the east end of the present Powell Valley anticline the forward movement on the lower gliding plane was sufficient to form a narrow anticline; and still farther east the thrusting occurred only along the upper of the two gliding zones, so that no anticline was formed.

Confidence in the foregoing interpretation of the nature of the thrusting is heightened by the discovery, in the southeast corner of the map in the Maynardville folio, of a structure section, reproduced as Figure 7, showing a beveled remnant of a structure such as that shown on Butts' cross section (Fig. 3), at and immediately north of



FIG. 7.—Reproduction of structure section from southeast corner of Maynardville folio. Note shape of thrust plane at left and manner in which strata dip into thrust plane along flat part of its course. Compare with cross section of Cumberland block (Fig. 3) in area northwest of fensters.

the fensters, and also on the model (Fig. 6), where the thrust breaks from the lower gliding plane up to the higher. This structure section proves that the type of thrust plane and thrust movement indicated for the Cumberland block is not unique, but occurs in connection with other faults of the Appalachian valley.

CROSS FRACTURES IN CUMBERLAND BLOCK

As has already been mentioned (Fig. 1), the Cumberland block is broken across by at least three lines of disturbance—one between Speedwell and Jellico, another between Cumberland Gap and Pineville, and a third extending from the eastern end of the Powell Valley anticline near Little Stone Gap northward toward Pine Mountain at Pound Gap.⁹

These lines of disturbance cross the block in directions which make the same angles with the Pine Mountain fault and with the block as a whole as the tear faults at its ends—essentially shearing

⁹ See map accompanying the report of J. Brian Eby and others, "The Geology and Mineral Resources of Wise County and the Coal-Bearing Portion of Scott County, Virginia," *Virginia Geol. Survey Bull.* 24 (1923).

angles. The most southwesterly of these lines of disturbance extends diagonally northwestward across the block from the vicinity of Speedwell toward Jellico. No adequate description of the details of its structure has been found; but, as inferred from a meager description¹⁰ and from the geological map of Tennessee, it seems to be a line of rather sharp monoclinal dip northeast, so that the portion of the block southwest of this line stands somewhat higher structurally than that on the northeast. The trend of the disturbed zone appears to be about northwest. The zone has the appearance of an incipient tear fault separating an area of somewhat greater thrust movement in the Cumberland block west of it from one of less movement on the east.

The middle one of the three cross zones of disturbance is the Rocky Face fault zone extending from Cumberland Gap northward toward Pineville, and trending approximately parallel with the Jacksboro tear fault at the end of the block. It has been described by Ashley and Glenn¹¹ and certain of its implications discussed by Rich.¹² At Rocky Face it is essentially a buckled half dome on the east side of a fault upthrust toward the northwest.

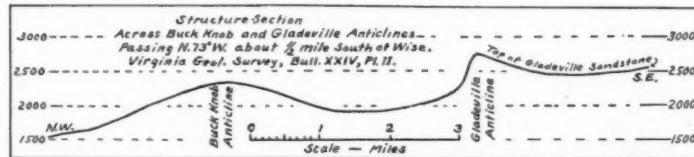


FIG. 8.—Profile across Buck Knob and Gladeville anticlines showing asymmetry of latter.

The third disturbed zone crosses the block northward from the point where the Powell Valley anticline dies out. It has been described and mapped by structure contours.¹³ It consists of two parallel anticlines, the Buck Knob anticline and the Gladeville anticline, whose forms and relations to each other are shown in cross section in Figure 8. The eastern of these, the Gladeville anticline, is very unsymmetrical, being steep on the west side. It is marked by two sharp subsidiary domes along its crest.

¹⁰ L. C. Glenn, "Northern Tennessee Coal Field," *Tennessee Geol. Survey Bull. 33-B* (1925).

¹¹ G. H. Ashley and L. C. Glenn, *op. cit.*

¹² John L. Rich, "Physiography and Structure at Cumberland Gap," *Bull. Geol. Soc. America*, Vol. 44 (1933), pp. 1219-36.

¹³ J. Brian Eby and others, *op. cit.*

All these cross fractures are believed to be superficial features of the Cumberland thrust block, representing a tendency toward breaking into segments as the block was pushed northwestward, and it is believed that all these cross fractures and folds will be found to end downward at the thrust plane underlying the block.

It seems that the formation of the Buck Knob and Gladeville anticlines can be accounted for by the excess northwestward shoving of that portion of the block east of the end of the Powell Valley anti-

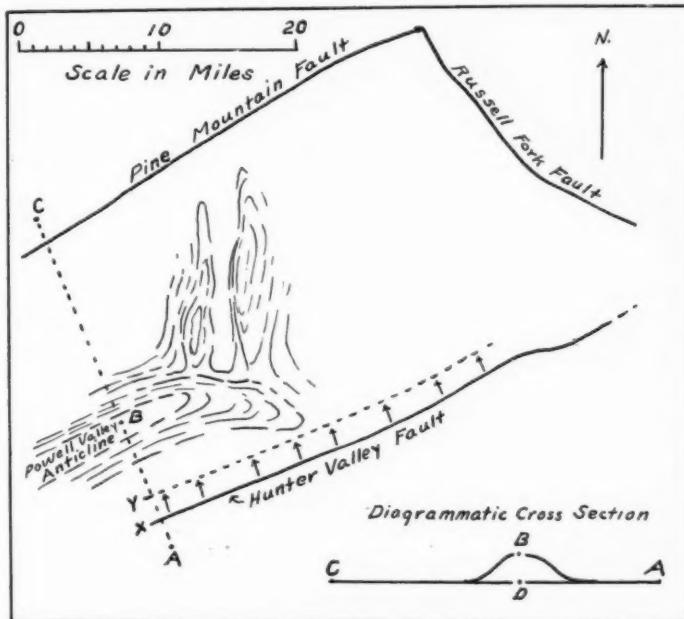


FIG. 9.—Sketch map of eastern end of Cumberland block to illustrate discussion of origin of Buck Knob and Gladeville anticlines. General form of anticlines indicated by sketch structure contours.

cline. Assuming that the Powell Valley anticline was formed during the thrusting, and as a result of the shearing up of the thrust plane from a lower bed to the horizon of the Chattanooga shale, and further assuming a uniform push from the southeast and a movement which may be diagrammatically represented by the distance XY (Fig. 9); then the northwestward movement of a point north of the anticline must have been less than XY by an amount equal to the difference

between the length of a line such as *ABC* over the top of the anticline, and a straight line *ADC* (see cross section, Fig. 9), whereas east of the end of the Powell Valley anticline the northwestward movement would have been the full amount, *XY*.

The beds east of the end of the anticline, being crowded northwestward in this way farther than those on the west, must have tended to tear loose along a shearing plane or incipient tear fault, forming a block of the same general shape as the Cumberland block as a whole. In view of the trend of the incipient tear fault, the excess northward movement of the area east of the end of the Powell Valley anticline must have produced a wedging effect similar to that which caused the upthrusting along the Jacksboro tear fault at the southwestern end of the Cumberland block. In this case, the movement seems not to have gone far enough to form an actual break, but only enough to form the highly unsymmetrical Gladeville anticline and the Buck Knob anticline in front of it.

The extreme sharpness of the Gladeville anticline and its asymmetry suggest strongly that it may pass downward into a thrust fault. The anticline bears many points of similarity to the Rocky Face fault zone near Cumberland Gap, even to the presence of sharp local domes along its crest, but it differs in that it has not been so far developed.

PROBABLE SHALLOWNESS OF LOCAL STRUCTURES IN CUMBERLAND BLOCK

The exposure of the fensters in the Cumberland block (Fig. 1) seems to make inevitable Butts' conclusion that the entire Cumberland block is underlain by a low-angle thrust plane and that the Pine Mountain fault marks the line along which the thrust plane sheared upward to the surface.

If the whole block is underlain by a thrust plane, it seems probable that any local anticlines or synclines appearing within the block are only superficial and do not extend down below the thrust plane which, as nearly as can be judged at present, follows the approximate horizon of the Chattanooga shale. There seems to be no reason to expect that such features as the Rocky Face half-dome or the Buck Knob or Gladeville anticlines extend below the thrust, especially since, as in the latter case, the presence of such features in the rocks above the thrust seems to be required by the dynamics of the thrusting.

BROADER ASPECTS—POSSIBLE CORRELATION OF PINE MOUNTAIN FAULT
WITH SEQUATCHIE VALLEY ANTICLINE

Analogy with the features displayed by the Cumberland over-thrust block strongly suggests that the Sequatchie Valley anticline¹⁴ is the expression of similar low-angle thrust faulting carried not so far as in the Cumberland block. The Sequatchie anticline, where eroded most deeply, reveals thrust faulting in its lower part; its distance from the western margin of the Appalachian Valley belt of strong shingle-type thrust faulting is comparable with that of the Pine Mountain fault; and the anticline west of Lookout Mountain in the southern part of the area occupies a position analogous to that of the Powell Valley anticline.

It is not difficult to picture a somewhat greater original movement along the thrust plane bringing the thrusts now exposed in the deeper parts of the Sequatchie anticline up to the surface (before erosion), shoving Walden Plateau farther westward, breaking it loose along a diagonal tear fault somewhere north of Pikeville, Tennessee, and producing an overthrust block almost identical with the Cumberland block.

BROADER BEARING ON GENERAL PROBLEM OF OVERTHRUST FAULTING

Revelation of the way in which thrust faults may follow for long distances along the bedding of strata, such as shales, on which movement is easy, completely changes the basis of calculations of the possible distance the rocks may move on overthrust faults. In the past such calculations have been based on the coefficient of friction of dry granite. The friction involved in movement along the bedding of clay shales, probably wet with water at the time of movement, is something of an entirely different order than that for granite.

Wentworth, for example, made a calculation of the force required to move the Cumberland block,¹⁵ but he used the coefficient of friction of dry granite. His results would have been radically different had they been based on movement along the bedding of shales.

Recognition of the importance of thrusting along bedding planes throws a new light on many problems in thrust faulting. For example, the striking fact that in crossing the Appalachian valley southeast-

¹⁴ The Sequatchie Valley anticline, as conspicuously shown on the geologic maps of Tennessee and Alabama, forms a remarkable anticlinal valley essentially in line and trend with the Pine Mountain fault, though separated from it by a gap of nearly 50 miles. The portion of the Allegheny Plateau between Sequatchie Valley and the Appalachian Valley province is known as Walden Plateau.

¹⁵ Chester K. Wentworth, *op. cit.*

ward from the Cumberland block toward the great up- and over-thrust mass of the crystalline Appalachians one passes half a dozen or more large thrust faults which bring up repeatedly, shingle-fashion, almost the whole of the unmetamorphosed Paleozoic sedimentary series without once bringing up the crystalline basement, makes it appear likely that the thrusting in that part of the Appalachian valley is entirely confined to the sediments, which have been sheared off from the underlying crystalline basement, pushed forward, and piled up in shingle-fashion by a great plunger moving from the southeast—presumably the pre-Cambrian mass of the crystalline Appalachians—which came up diagonally along a shear plane to the base of the sediments, then rode forward horizontally, pushing and piling up the sediments before it. It is not unlikely that the pre-Cambrian basement beneath the Appalachian valley would be found to be undisturbed.

PRE-PENNSYLVANIAN STRATIGRAPHY OF NEBRASKA¹

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ABSTRACT

Sioux quartzite, granite, and schistose metamorphic rocks have been recognized in the pre-Cambrian. The present irregularities, the "basins and highs," on the pre-Cambrian surface are the result of erosion and a long structural history. In general successively younger rocks rest unconformably by overlap against the pre-Cambrian "highs." The principal erosional and structural "highs" are: the "Nemaha mountains," the Cambridge anticline, the Chadron dome, and the Sioux Falls area. "Basins," or saddle-like depressions, occur on the pre-Cambrian surface between the "highs." The largest of these trends from southeast to northwest across the central part of Nebraska. The history of each ridge or "high" is more or less individualistic, but it seems certain that the structural framework of Nebraska came into existence in late pre-Cambrian time and has dominated the structural and depositional history of the state ever since.

Every Paleozoic system below the Pennsylvanian is represented by identifiable rocks in the subsurface section of Nebraska, and all are present at least east of the buried Nemaha ridge. The exact subsurface distribution of each of the Paleozoic systems is not yet known with certainty. Apparently all formations are the same and are continuous with the pre-Pennsylvanian rocks of Iowa. The Cambrian and Ordovician rocks of the southern part of the state are also quite similar to correlative formations in Oklahoma. The fact that most of the deep test wells so far drilled in the state have been located on structural or on monadnock-like pre-Cambrian "highs" has precluded the discovery of many pre-Pennsylvanian Paleozoic rocks, which do occur in the "basins." This has led to the misconception that Nebraska was not invaded by all of the Paleozoic inundations.

PART I. PRE-CAMBRIAN

Knowledge of the pre-Cambrian rocks under Nebraska is entirely too meager to justify definite conclusions regarding details of their lithologic character, distribution, present relief, and structural interpretations. However, ten deep drillings, tests for oil and gas, have reached the pre-Cambrian in Nebraska at depths ranging from 558 feet (DuBois) to 4,526 (Holdrege), and at one place (Holdrege), penetrated more than 1,150 feet of the ancient crystalline schist. Several wells in southeastern South Dakota, which reached the Sioux quartzite, are of value in understanding the pre-Cambrian configuration under Nebraska. The deep test at Norcatur, Kansas (Marland Oil Company), which reached pre-Cambrian granite, and several wells

¹ Presented before the Kansas Geological Society, Sixth Annual Field Conference, September 2, 1932. Published by permission of G. E. Condra, State geologist of Nebraska. Manuscript received, April 9, 1934.

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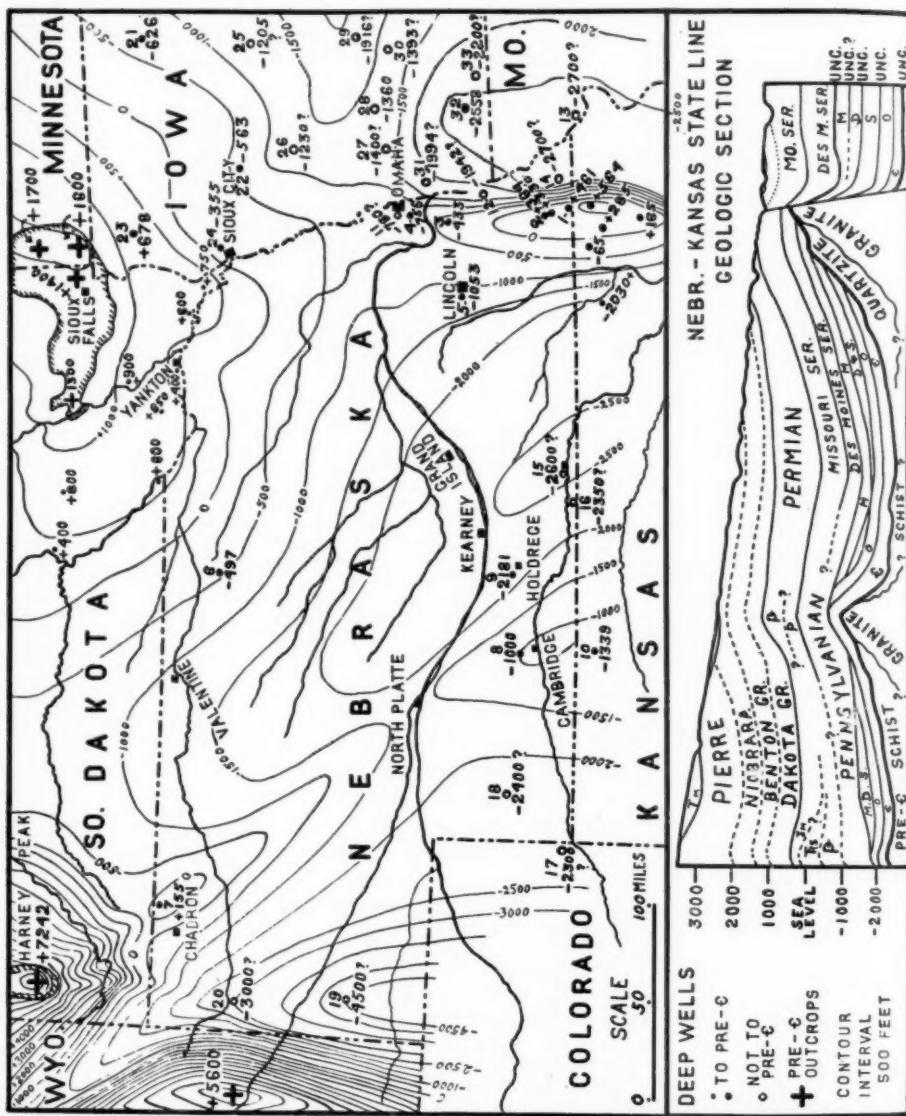


FIG. 1.—Contour map of pre-Cambrian surface.

in northeast Kansas have been used in this connection. In addition to the deep tests which actually reached the ancient crystalline basement rocks, eight other wells in Nebraska, one in Colorado (Phillips Petroleum Company, George Andrews No. 1), and one in Missouri (Forest City), penetrated deeply enough into the Paleozoic rocks to warrant using such data as their logs yield, to base tentative conclusions on regarding the depth and elevations of the pre-Cambrian. Five pre-Cambrian wells and eight others in western Iowa also have been used. Knowledge of the near-by pre-Cambrian outcrops at Sioux Falls, where the Sioux quartzite (Huronian) crops out, the Black Hills, where granite and other highly metamorphosed quartzites and schists crop out, in South Dakota, and the pre-Cambrian outcrop of schist and iron ore at Hartville, Wyoming, is also drawn on in the preparation of this paper.

Essential data on the aforementioned locations are given in the tables which follow. Elevations of pre-Cambrian which are below sea-level are indicated by a minus sign in front of the number. These data, together with some unpublished information, are used on which to base the pre-Cambrian contour map, drawn with a 500-foot contour interval (Fig. 1).

Nearly all essential data are taken from "Deep Wells of Nebraska," by G. E. Condra, E. F. Schramm, and A. L. Lugin, *Nebraska Geological Survey Bulletin 4*, Second Series (1931). The data from Iowa wells are from the Iowa Geological Survey, Volumes XXI (1912) and XXXIII (1927).³ Several Kansas Geological Survey publications and N. H. Darton's "Geology and Underground Water Resources of the Central Great Plains," *United States Geological Survey Professional Paper 32*, are also used. E. F. Schramm published a small map, more inclusive than that included here, and a table of data on pre-Cambrian wells in "Deep Wells of Nebraska," pages 281-86, of special interest in connection with this subject.

LITHOLOGY

Carefully taken cuttings or core samples have been petrographically examined from seven of the pre-Cambrian wells of this state, and, at least in these cases, the nature of the old rock is accurately known. The best samples of pre-Cambrian rock so far preserved are from the Nehawka (Amerada Petroleum Company) and from the Victor Jeep well near Papillion, numbers 3 and 4, in tables I and II and on

³ Additional data on the Clarinda, Iowa, well number 32, were supplied to the writer by Anthony Folger, after the manuscript had been submitted for publication. The necessary corrections have been made.

the map (Fig. 1). Sioux quartzite was encountered in both of these tests. Its lithologic character is pinkish, reddish-to-grayish brown quartzite, not unlike the pink quartzite boulders found in eastern Nebraska in the glacial drift where the Nebraskan or Kansan glacier

TABLE I
PRE-CAMBRIAN OF NEBRASKA*
DEEP WELLS WHICH REACHED PRE-CAMBRIAN (FIGURES IN FEET)

No.	Name	Surface Elevation	Depth of Well	Depth to Pre-Camb.	Pre-Camb. Elevation
1	Du Bois	1,019	565	558	461
2	Table Rock	1,114	765	750	364
	Table Rock	1,030	1,500	700	330
3	Nehawka	1,134	1,828	1,567	-433
4	Victor Jeep	1,114	1,909	1,870	-756
5	Lincoln (Capitol Beach)	1,140	2,463	2,193	-1,053
6	Bassett	2,323	2,965	2,820	-497
7	Duthie	3,025	2,947	2,870	155
8	Watkins	2,360	3,423	3,360	-1,000
9	Holdrege	2,345	5,678	4,526	-2,181
10	Norcatur (Kansas)	2,591	3,986	3,930	-1,339
 DEEP WELLS WHICH DID NOT REACH PRE-CAMBRIAN (FIGURES IN FEET)†					
11	Lane	1,091	1,829	1,871 ±	780 ±
12	Nebraska City	932	2,874	2,874 ±	-1,942 ±
13	Forest City, Mo.	856	2,500	3,550 ±	-2,700 ±
14	Salem (Morgan)	1,030	3,310	3,730 ±	-2,700 ±
15	Price	1,727	3,446	4,327 ±	-2,600 ±
16	Ohio (Avery)	2,003	4,252	4,353 ±	-2,350 ±
17	Phillips (Colorado)	3,443	5,130	5,743 ±	-2,300 ±
18	Imperial (Ingold)	3,214	4,355	5,614 ±	-2,400 ±
19	Harrisburg	4,500	5,697	9,000 ±	-4,500 ±
20	Agate	4,520	4,554	7,520 ±	-3,000 ±

* Data from "Deep Wells of Nebraska," *Nebraska Geol. Survey Bull.*, 4, 2d Ser. (1931).

† The estimated depths to the pre-Cambrian and the estimated elevations of the pre-Cambrian are based on very problematical data. These estimates are meant to be only suggestive and some of the figures may be greatly in error. The errors in the figures for wells numbered from 11 to 16 inclusive may be only a few scores of feet but those for wells numbered 17 to 20 inclusive may range from 500 to 1,000 feet.

left them after having transported them from the Sioux Falls "high" of exposed quartzite.

The Sioux quartzite was cored for 261 feet in the Nehawka (Amerada) well and penetrated to a depth of 39 feet in the Victor Jeep well. Conglomeratic and consequently somewhat "arkosic" quartzite has been drilled into at some horizons and because of its apparent "arkosic" nature has been confused with granite. However, boulders of just such conglomeratic "arkosic" quartzite also can be found in the drift or seen in place in the Sioux Falls area.

Reddish quartzite seems to have been penetrated for a depth of 270 feet, 3 inches, according to the published log, in the Capitol

Beach well at Lincoln. B. P. Russell,⁴ geologist in charge, in his report of December 1, 1888, stated: "I am not prepared to state that this is the Sioux quartzite but all admit that there is a strong resemblance between them." There was no doubt in Russell's mind, with the core before him, that it was quartzite and he apparently was convinced that it was Sioux in age, probably Upper Huronian. This

TABLE II

No.	Name	Kind of Rock	Location†
1	Du Bois	Granite	SE. of Du Bois in Sec. 25, T. 1 N., R. 12 E.
2	Table Rock (two wells)	Granite	NW. Cor. Sec. 12, T. 2 N., R. 11 E. NE. $\frac{1}{4}$ Sec. 29, T. 3 N., R. 12 E.
3	Nehawka	Quartzite	NE. Cor. Sec. 26, T. 11 N., R. 12 E.
4	Victor Jeep	Quartzite	NW. of SE. Sec. 23, T. 14 N., R. 12 E.
5	Lincoln	Quartzite	Capitol Beach, west side of Lincoln
6	Bassett	Schist	East edge of town of Bassett
7	Duthie	Schist	18 miles NE. of Chadron, Sec. 33, T. 35 N., R. 47 W.
8	Watkins	Granite	Sec. 13, T. 5 N., R. 26 W.
9	Holdrege	Schist	$\frac{5}{4}$ miles NW. Holdrege, SW. $\frac{1}{4}$ Sec. 23, T. 6 N., R. 19 W.
10	Norcatur (Kansas)	Granite	NW. Cor. Decatur Co., Kan., Sec. 25, T. 2 S., R. 26 W.
11	Lane	Cambrian	Lane Station, west of Omaha, Nebraska
12	Nebraska City	Cambrian ? or quartzite	SW. $\frac{1}{4}$ Sec. 10, T. 8 N., R. 14 E.
13	Forest City (Missouri)	Silurian	3 or 4 miles SE. of Forest City, Mo.
14	Salem (Morgan)	Ordovician or Cambrian	SE. of NE. Sec. 26, T. 1 N., R. 14 E.
15	Price	Mississippian	SW. of town of Red Cloud, Neb., Sec. 3, T. 1 N., R. 11 W.
16	Ohio (Avery)	Cambrian	Near Riverton, Neb., NE. of SE. Sec. 30, T. 1 N., R. 13 W.
17	Phillips	Pennsylvanian	Yuma County, Colo. (SW. Cor. Dundy Co., Neb.) SE. of Wray, Colo., on Arkansas R.
18	Imperial	Pennsylvanian	3 miles SE. of Imperial, Neb.
19	Harrisburg	Graneros	4½ miles E. and 1½ miles N. of Harrisburg.
20	Agate	Graneros	NE. Cor. Sec. 15, T. 28 N., R. 55 W.

† The method of naming and recording the locations of wells used in this paper is not the method in general use by Mid-Continent geologists, but is the same as employed in "Deep Wells of Nebraska," *Nebraska Geol. Survey Bull.* 4, 2d Ser. (1931). It is thought that this will facilitate reference to the logs published in that bulletin.

old core is still preserved in the Nebraska State University Museum, but the writer and other geologists have been denied access to it.

Sioux quartzite may also have been reached in the Brick Plant well at Nebraska City, number 12, a test not generally credited as having reached the pre-Cambrian. If the bottom of this hole was not

* "Deep Wells of Nebraska," p. 150.

actually in quartzite it was undoubtedly within a very few feet of it. Other wells in this part of the state, in and near Omaha, have penetrated nearly to the pre-Cambrian, which it is thought would have been Sioux quartzite.

No wells reach the pre-Cambrian in the northeast corner of this state, but that area also is undoubtedly underlain largely if not wholly with the Sioux quartzite, which has been found in every pre-Cambrian

TABLE III
PRE-CAMBRIAN OF WESTERN IOWA*
DEEP WELLS WHICH REACHED PRE-CAMBRIAN (FIGURES IN FEET)

No.	Name	Surface Elevation	Depth of Well	Depth to Pre-Camb.	Pre-Camb. Elevation
21	Algona	1,204	1,885 in granite	1,830	-626
22	Holstein	1,457	2,040 in granite	2,020	-563
23	Hull	1,433	1,263 quartz-porphyry and quartzite†	755	678
24	Sioux City	1,125	2,011 in schist (?)	1,480	-355
32	Clarinda§	1,012	5,275	3,570	-2,558
DEEP WELLS WHICH DID NOT REACH PRE-CAMBRIAN (FIGURES IN FEET)‡					
25	Gowrie	1,137	1,842 in Silurian	2,342±	-1,205±
26	Denison	1,170	1,810 in Prairie du Chien	2,400±	-1,230±
27	Oakland	1,102	1,936 in Silurian or Ordovician	2,500±	-1,400±
28	Atlantic	1,150	1,310 in Devonian	2,510±	-1,360±
29	Stuart	1,205	3,021 in Cambrian	3,121±	-1,916±
30	Greenfield	1,370	2,505 base Ordovician?	2,710±	-1,393±
31	Glenwood	1,031	2,200 in Silurian	3,025±	-1,994±
33	Bedford	1,098	2,400 near base Silurian	3,300±	-2,200±

* Data from *Iowa Geol. Survey*, Vols. XXI (1912) and XXXIII (1927); also from *U. S. Geol. Survey Water-Supply Paper 293*.

† In places in northwestern Iowa, the pre-Cambrian quartzite is cut by numerous igneous sills. See *Iowa Geol. Survey*, Vol. XXI (1912), p. 1008.

‡ The estimated depths to the pre-Cambrian and the estimated elevations of the pre-Cambrian in wells 25 to 33 inclusive are not to be regarded as accurate but as only suggestive. Some may be greatly in error.

§ The Clarinda well was first tabulated as not having reached the pre-Cambrian, but corrections supplied by Anthony Folger have made it necessary to place number 32 with the deep wells which reached pre-Cambrian.

|| Still drilling, April 21, 1933.

well in northwest Iowa and in southeast South Dakota, supported by the additional evidence of the large area of exposed Sioux quartzite in the vicinity of Sioux Falls, South Dakota. According to Norton,⁵ the pre-Cambrian quartzite is cut by numerous igneous sills in northwestern Iowa. Some may be dikes or other intrusive forms.

The pre-Cambrian rock reported in three deep tests has been schist.

⁵ *Iowa Geol. Survey*, Vol. XXI (1912), p. 1008.

They are at Bassett, the Duthie well at Chadron, and at Holdrege (Trees Petroleum Company's Bergman No. 1).⁶

Samples from only the bottom 145 feet of the Bassett well number 6, were recovered and examined. All were of pre-Cambrian rock but above this bottom 145 feet there is a gap in the record, where samples are missing for 275 feet. Hence, the pre-Cambrian may have been entered at a somewhat shallower depth than 2,820 feet or slightly above 497 feet below sea-level. The pre-Cambrian of this test is regarded as a hornblende schist, but it may be significant that the upper part of it contained "numerous sub-rounded to subangular frosted quartz grains" and seemed to be "very sandy." This suggests that the uppermost material of the pre-Cambrian may be quartzite resting on the older and lower hornblende schist. The schist contains hornblende, pyroxene (?), biotite, and undetermined minor and accessory minerals, including some magnetite. Hornblende is the predominant mineral. The United States Geological Survey has corroborated the correlation of the schist from this test.

Dark gray, very hard and micaceous schistose pre-Cambrian rocks were entered below the Deadwood formation (Cambrian) in the Duthie well, 18 miles northeast of Chadron, number 7. The crystalline rocks were entered at a depth of 2,870 feet or at 155 feet above sea-level and drilled into to a depth of 77 feet.

The pre-Cambrian crystalline rock was penetrated for a depth of 1,152 feet in the Holdrege well (Trees Petroleum Company's Bergman No. 1), number 9. It was entered at a depth of 4,526 feet or at 2,181 feet below sea-level. The upper 27 feet consists of quartzitic mica schist, the remaining 1,125 feet is made up of thicker and thinner zones of mica schist, gneissoid granite (or gneiss), binary granite, hornblende granite, and amphibolite. It seems probable that the igneous zones in this section may be sills, dikes or other injected forms intrusive into the ancient schists.

Granite has been reported from the two deep tests at Table Rock, at Du Bois, and at Cambridge (Watkins well) in Nebraska and also from the Norcatur well in Kansas.

Pink, very feldspathic granite has been reported from the Norcatur well, number 10, and similar pink granite was examined by the writer from the Watkins well northwest of Cambridge, number 8. These two wells apparently are both located on or near the crest of the Cambridge anticline, which seems to contain a core of pink feldspathic granite.

* The log of the Holdrege (Bergman) well has not yet been published.

Similar pinkish feldspathic granite has been reported from the two wells at Table Rock and at Du Bois in Nebraska and also from several wells southward into Kansas. The depth to the pre-Cambrian (granite) in the Du Bois well was only 558 feet or at an elevation of 461 feet above sea-level, the highest point so far known on the Nemaha ridge in Nebraska. There may be some doubt as to the exact identification of this rock as massive granite, as is usually implied. It may be massive granite as indicated by the record of one of the Table Rock wells, number 2, where it was first reached at a depth of 700 feet and drilled into for almost another 800 feet, "in the hope that only a sill or shelf of granite has been encountered." The granite here and southward into Kansas may indeed be a large subjacent injection or even a batholith, probably of pre-Cambrian age, not unlike the Harney Peak granite batholith of the Black Hills.

PRE-CAMBRIAN SURFACE

The accompanying contour map is an attempt to represent the pre-Cambrian surface as it would now appear if all overlying formations were removed. It is not implied that the configuration of this ancient surface has always been the same, as will be discussed later. The contours are drawn to show at least the major relief features on a 500-foot contour interval. Many minor relief features naturally escape representation with a 500-foot contour interval, also many features have no doubt escaped detection because of lack of subsurface data. Test wells are indicated by numbers, as previously used in the preceding tables, and sea-level elevations on the pre-Cambrian are also tabulated on the map. Pre-Cambrian elevations which are below sea-level are indicated by a minus (-) sign. No great accuracy is claimed for this map but it is hoped that it represents faithfully such data as are available.

G. E. Condra has discussed the "Highs and Basins"⁷ of Nebraska briefly and also published a map showing the locations of the major pre-Cambrian features known to occur under this state. He also has discussed briefly the "Relation of the Platte Section to pre-Cambrian Bedrock Features."⁸ Condra's map and the present contour map agree on all major features.

The northeast part of the state is undoubtedly underlain by Sioux quartzite, as previously noted, and the large, high area of exposed

⁷ G. E. Condra, E. F. Schramm, and A. L. Lugh, "Deep Wells of Nebraska," *Nebraska Geol. Survey Bull.* 4, Second Ser. (1931), pp. 15-17.

⁸ G. E. Condra, "Correlation of the Pennsylvanian Beds in the Platte and Jones Point Sections of Nebraska," *Nebr. Geol. Survey Bull.* 3, Second Ser. (1930), pp. 54-56.

quartzite in the Sioux Falls region dominates the substructure of surrounding areas. Undoubtedly there is considerable relief on the old quartzite surface and in addition to minor relief features there seem to be large ridge-like and wide valley features radiating away from the area of exposure into northwestern Iowa, northeastern Nebraska, and eastern South Dakota. It would also seem likely that this large high area is connected on the south with the buried Nemaha mountains or "Granite (?) ridge" in the southeastern part of the state. The continuity of this ridge with the Sioux Falls "high" is interrupted by a saddle north and northwest of Omaha, as indicated on the map. There is some evidence to indicate the presence of a secondary small "high" or structure northwest of Omaha.

Succeedingly younger systems of rock rest unconformably against the flanks of the Sioux Falls "high" by overlap, implying their deposition higher and higher against the quartzite during its existence as an island in the Paleozoic and Mesozoic seas.

The Nemaha ridge is perhaps the most interesting feature of the pre-Cambrian surface under Nebraska. Its configuration and relief are shown on the map. Convincing evidence has now accumulated to show that the steep east slope is a fault scarp, with a relief of more than 3,100 feet in a horizontal distance of about 13 miles between the well at Du Bois, number 1, and the Salem well, number 14, in the Brownville-Forest City basin. Busby⁹ has shown that the displacement of Pennsylvanian beds at some points along this fault, known as the Humboldt fault, is as much as 250 feet. The displacement along the same fault or zone of faults of lower and older Paleozoic formations, where the same beds occur over the ridge and also in the basin, is several times this amount. The younger systems of rock rest unconformably against the pre-Cambrian Sioux quartzite and granite by overlap, as was also noted in the case of the Sioux Falls pre-Cambrian "high." These facts will be referred to again later.

Condra¹⁰ has described the Nemaha mountains as follows.

Granite (?) Ridge: An area in western Richardson County and eastern Pawnee County and extending southward and southwestward through Kansas, past Seneca, Beattie, Blue Rapids, Wamago, Zeandale and Eldorado, is underlain by granite at a comparatively shallow depth. This high, pre-Cambrian ridge has been described by Dr. R. C. Moore as the Nemaha Mountains. It is a buried structural feature in the Table Rock and related anticlines.

⁹ C. E. Busby, "A Detailed Study of the Table Rock Anticline and the Humboldt Fault in Southeastern Nebraska," unpublished thesis, University of Nebraska Library, Lincoln, Nebraska.

¹⁰ "Deep Wells of Nebraska," p. 132.

The Paleozoic formations are quite thick, in each flank of the Table Rock anticline up to near the borders of the granite ridge. This is well shown by wells drilled in Nebraska and Kansas. The condition on the east is shown by the Du Bois and Salem wells of Nebraska, and that on the west is shown by the Blue Rapids and Marysville wells of Kansas. A well about four miles northeast of Blue Rapids, Kansas, reached crystalline rocks at probably 1,600 feet whereas a well about 2 miles south of Marysville was yet in the Paleozoic beds when abandoned at 2,335 feet.

The Brownville-Forest City basin, which extends into the extreme southeastern corner of Nebraska is the most notable basin feature of the eastern part of the state. It is probably definitely separated from another basin which extends northwestward from south-central Iowa toward the saddle feature north of Omaha, already noted. This is shown on the map (Fig. 1).

Southwestward from the Sioux Falls high and westward from the Nemaha ridge, the pre-Cambrian surface slopes gradually into the great central Nebraska basin which extends southward into Kansas and northward into South Dakota. Since almost no data are available from this great central basin area, little is known of either the pre-Cambrian configuration under it or of the Paleozoic formations that may occur in it.

The central basin is limited on the southwest by the Cambridge anticline, wells 8 and 10 on the map, and on the northwest by the Chadron "dome" and the Black Hills as indicated on the map. The continuity of the Cambridge and Chadron "highs" or structures across the state as suggested by the contours, is largely hypothetical. However, additional evidence in support of such a structural connection was obtained during the 1932 field season, when it was found that the Niobrara formation lies directly under the Tertiary beds a few miles east of the town of North Platte. This indicates that an anticlinal structure extends under the Platte Valley at this point, since Pierre shale occurs east of this point nearly as far as Grand Island, and west of the high point on the Niobrara, the Pierre shale dips southwestward. This may indicate a ridge or core of pre-Cambrian rock in this long anticline across the state as suggested on the map.

Structures in the Cretaceous and underlying older formations down to and including a part of the Pennsylvanian system near the southwest corner of the state (Phillips Petroleum Company's George Andrews No. 1, number 17 on the map) indicates a reversal of dip and the existence of an anticline in this area. There is no evidence to show that this structure reflects a "high" on the pre-Cambrian, but if it does, it falls within the 500-foot contour interval and is not in-

dicated on the map. Westward of this the pre-Cambrian floor slopes steeply into a deep basin in northwestern Colorado. This basin extends across the western end of Nebraska and northwestward into Wyoming between the Black Hills and the Hartville uplift.

TOPOGRAPHIC AND STRUCTURAL INTERPRETATION

The major relief features on the pre-Cambrian floor under Nebraska and adjacent areas, as previously described, are believed first to have come into existence near the close of the pre-Cambrian time itself, probably in late or post-Huronian time. It seems probable that the Sioux Falls "high" and other positive features like the Nemaha ridge and possibly even the Cambridge anticline were first elevated into some prominence during the orogeny which brought the Proterozoic era to a close. This disturbance is commonly known as the Killarney-Grand Canyon revolution. There may even have been a structural as well as a generic connection between these ancient north mid-continent structural features and the long and prominent Killarney Mountains, which are supposed to have extended from northern Minnesota northeastward to the Atlantic.

The relative age of the pre-Cambrian schist, quartzite, and granite under Nebraska can not be determined, but some evidence has already been given to suggest that the quartzite (Sioux) is younger than the schist. However, the quartzite may be more or less equivalent in age to the schist and may have a more or less interlayered or interfingered relation to the latter. The quartzite may have been deposited as sand and gravel nearer the ancient shore lines and the schist may have been, at least in part, more or less contemporaneous fine-textured sediment laid down more remote from the source areas on the northeast. Volcanic products may have been contributed to the complex from time to time in some places.

Granitic sills, dikes, et cetera, were undoubtedly intruded into the metamorphic series during or following the major orogenic events. The granite of the Nemaha mountains, the "Granite ridge" of southeastern Nebraska and Kansas, is undoubtedly of pre-Cambrian age and it seems probable that it was intruded into the somewhat older schist and quartzite at the same time and later uncovered by erosion. The same may be true of the granite in the Cambridge anticline. The large extent and volume of buried granite, especially in Kansas, suggests that it may be a pre-Cambrian batholith, not unlike the Harney Peak batholith of the Black Hills, with sills, dikes, et cetera, emanating from the parent igneous mass.

The initial faulting along the east face of the Nemaha mountains

must have taken place contemporaneously with or following the subjacent injection of the granite. An alternative assumption is that the granite is the oldest rock, was peneplaned, and then more or less covered with sediment which had since been metamorphosed and the whole complex later faulted prior to Cambrian time.

Additional faulting has taken place along the same rifts at several later periods during the Paleozoic era. This will be more fully discussed later.

A period of weathering and erosion, possibly even of peneplanation, followed the appearance of these prominent topographic features, as the Sioux Falls "high," the Nemaha mountains, et cetera, prior to the more or less complete marine inundations of the region during the Paleozoic era. All of the details of this early history are indistinct and may never be fully known, but it is clear that monadnock-like topographic and structural high areas or ridges featured the early Cambrian landscape of this region. The basins received their earliest Paleozoic sediments during late or upper Cambrian time, the epoch during which the Cambrian flood attained its maximum extent in that period.

Proof of the monadnock-like character of the buried pre-Cambrian "highs" and ridges is found in the unconformable overlap relations of the higher and younger formations and systems of rocks against and onto the ancient crystalline rocks. Deep wells east of the Nemaha ridge or low on its slopes in any direction usually penetrate several hundred feet of older strata which were not deposited over the crest of the ridge. These older strata, especially the lower Ordovician and Cambrian formations, thin out against the pre-Cambrian. Speaking of the Nemaha ridge in connection with the Platte section, G. E. Condra¹¹ says:

The rock systems younger than the Sioux quartzite in this general area, as shown by well logs, are the Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian and Cretaceous. Some of the lower Paleozoic formations thin out and overlap against the Sioux quartzite high. For example, the Cambrian beds occur well out on the east and north flanks of the buried substructure but disappear against the latter. This is also true of the lower units of the Ordovician.

The data in the table below and the figure which follows illustrate this interpretation of the Nemaha ridge. The Capitol Beach well at Lincoln is located approximately 38 miles west of the Amerada well at Nehawka and is relatively low on the pre-Cambrian slope. Ap-

¹¹ G. E. Condra, "Correlation of the Pennsylvanian Beds in the Platte and Jones Point Sections of Nebraska," *Nebr. Geol. Survey Bull.* 3, Second Ser. (1930), p. 54.

proximately 72 feet of Cambrian sandstone (Jordan) and 113 feet of lower Ordovician beds were deposited at Lincoln against the west flank of the Nemaha ridge before St. Peter time, when the sea extended over the ridge at Nehawka. South of Nehawka at the Table Rock and Du Bois vicinity the pre-Cambrian remained above water level until Pennsylvanian time. Between Nehawka and the Du Bois vicinity and between Lincoln and Du Bois, the entire Silurian, Devonian, Mississippian, and the lower part of the Pennsylvanian rest unconformably against the pre-Cambrian slope, each younger system overlapping beyond the older ones.

TABLE IV
SEA-LEVEL ELEVATIONS OF TOPS OF SYSTEMS OR FORMATIONS IN WELLS USED TO ILLUSTRATE STRUCTURAL HISTORY OF NEMAHА RIDGE
(Figures in Feet)

System or Formation	Lincoln (Capitol Beach) Curb Elevation 1140	Nehawka (Amerada) Curb 1134	Papillion (Victor Jeep) Curb Elevation 1114	Nebraska City (Brick Plant) Curb Elevation 932
Mississippian	+71* (601)†	+672*	+614*	(58)†
Devonian	-78 (488)	+410	+364	(46)
Silurian	-228 (653)	+365	+169	(196)
Maquoketa	-673 (395)	-278	-341	(63)
St. Peter	-807 (423)	-384	-454	(70)
Cambrian	-981 †	Absent	-606	§
Pre-Cambrian	-1053 (620)	-433	-756	(323)

* Sea-level figures are given to the nearest even foot, elevations above sea-level are headed by a plus (+) sign, and elevations below sea-level are headed by a minus (-) sign.

† Figures in parenthesis indicate the number of feet the top of any system or formation occurs lower in the well in question than the top of the same bed in the Nehawka (Amerada) well, located on top of the Nemaha ridge.

‡ A total of nearly 246 feet of St. Peter, lower Ordovician, and Cambrian beds occur in the Capitol Beach well, of which only 40 feet of St. Peter, resting on the Sioux quartzite, occur in the Nehawka well.

§ A total of 302 feet of St. Peter, lower Ordovician, Cambrian, and Red Clastic series occur in the Victor Jeep well, of which only 49 feet of St. Peter, resting on the Sioux quartzite, occur in the Nehawka well.

|| A total of 552 feet of St. Peter, lower Ordovician, and Cambrian beds occur in the Nebraska City well, of which only 49 feet of St. Peter, resting on the Sioux quartzite, occur in the Nehawka well.

The same relation exists between the Amerada well and the Victor Jeep well at Papillion, approximately 25 miles north of Nehawka. In the Jeep well 20 feet of Red Clastic series, 130 feet of Cambrian formations, and 115 feet of the Prairie du Chien group were deposited on the pre-Cambrian quartzite slope prior to St. Peter time, when the sea covered both the Jeep and Amerada locations.

The Brick Plant well at Nebraska City is located about 14 miles southeast of the Amerada location at Nehawka. It illustrates the same relations as the Jeep and Capitol Beach wells, and in addition, the subsequent Paleozoic faulting along the east face of the Nemaha

ridge. If the bottom of the Nebraska City well reached Sioux quartzite or nearly reached it, then at least 250 feet of Cambrian, and 272 feet of Ordovician beds below the St. Peter were deposited here prior to St. Peter time. These older beds were then deposited on the east flank against the pre-Cambrian slope and their thickness of more than 500 feet quite probably is a fair measure of the relief on the Sioux quartzite between Nehawka and Nebraska City at the time of the first Cambrian sedimentation at Nebraska City, since it seems logical to assume a relatively level St. Peter sea bottom. The relief on the pre-Cambrian surface from Du Bois eastward into the Forest City

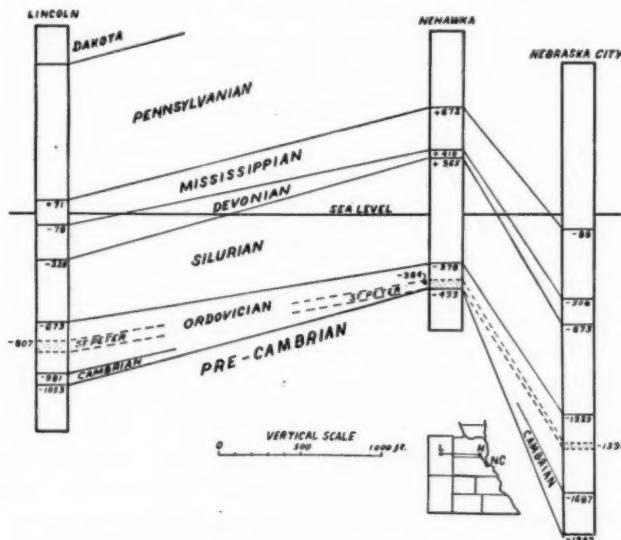


FIG. 2.—East-west relationships across pre-Cambrian Nemaha ridge.

basin must have been at least 1,000–1,500 feet greater at the same time. It may even have been much more than this.

The top of the St. Peter formation is now about 1,000 feet lower at Nebraska City than it is at Nehawka. It is thought that this is a result of subsequent displacement between these locations. Post-Pennsylvanian Permian faulting along the Humboldt fault has produced a displacement of 200–250 feet. The top of the Mississippian system is 760 feet lower at Nebraska City than at Nehawka; hence it seems reasonable to assume that the post-Mississippian displace-

ment may have been as much as 500 feet, and by similar reasoning the post-Devonian displacement may have been in the neighborhood of 100 feet. Likewise it is thought that there may have been as much as 50-100 feet of displacement along the old fault following Silurian and also following Ordovician sedimentation. The Ordovician is apparently conformable on the Cambrian. Unconformities occur above the Ordovician, Silurian, Devonian (?), and Mississippian systems and this fact may complicate the interpretation of the figures.

There is nearly twice as much Cambrian and lower Ordovician sediment below the St. Peter horizon at Nebraska City as at either Lincoln or Papillion. This is no doubt due to the greater depth of the basin at Nebraska City, which may have been a result of faulting accompanying or following the initial elevation of the Nemaha ridge. The fault passes east of Nehawka and Papillion, so that the Papillion and Lincoln locations have been raised from time to time with the whole Nemaha block. However, the block has also been tilted, raising points on its crest higher than points farther down on its western and northern slopes. This fact accounts for the St. Peter formation being 583 feet higher at Lincoln, and 936 feet higher at Papillion than at Nebraska City. The Papillion location is nearly on the crest of the ridge and has been elevated nearly as much as the Nehawka location.

Other pre-Cambrian "highs" and ridges, such as the Sioux Falls area, the Cambridge anticline, and the Chadron dome, probably have similar histories and all are believed to have had their beginning at or near the close of pre-Cambrian time. The subsequent history of each high or ridge may have been different and more or less individualistic, but it seems certain that the structural framework of Nebraska came into existence in late pre-Cambrian time and has dominated the structural and depositional history of the state ever since.

PART II. PRE-PENNSYLVANIAN PALEOZOIC ROCKS

Every Paleozoic system below the Pennsylvanian is represented by identifiable rocks in the subsurface section of Nebraska, and all are present at least east of the buried Nemaha ridge, previously discussed. The Cambrian, Ordovician, and Mississippian systems are known to occur west of this pre-Cambrian ridge, under the southern part of the state. However, every system except the Cambrian, if absent, is believed to be present in the Capitol Beach well at Lincoln. The Cambrian and Mississippian systems only are known to occur under the northwestern part of the state. The exact subsurface distribution of these rocks is not known with any accuracy. Also, the Silurian and

TABLE V
PRE-PENNSYLVANIAN SYSTEMS OF ROCK ENCOUNTERED IN DEEP WELLS IN NEBRASKA
(Thicknesses in Feet)

OMAHA*		MILLER Park		FORT Creek		SCHUYLER, PAFFITTION		MEEHADA, NEBRASKA		MURRAY, UNION		BRECK/LAUN, NEBRASKA CITY		OHIO, REEFERTON		DUDHIC, CHADRON		TREES, BREGMAN NO. 1, HOLDREGE†		MORGAN, SALTERMAN‡		MISISSOURI, FORTESI CITY, SALEM‡		AVERAGE		
Mississippian	220	292	346	356	250	230	261.5	292	420	149.6	310	410	110	+	419.1	290+										
Devonian	180	138	184	152	195	150	45.4	24?	165	209.25	Absent	Absent	Absent	+	324	160+										
Silurian	190	144+	368	202	510	560	643.08	326+	556	385.4	305	458	368	207	+	134.9+	427									
Ordovician	214+		272		265	158+	154.5				255	Absent?	102+	275	81	?	281+									
Cambrian			239+		130			Absent		?	71.5		?	?	?	?	185+									
Red Clastic					20					?	270.25+		77+	1,152+												
Pre-Cambrian						39+				?																

Note: All data in the table are taken from "Deep Wells of Nebraska," by G. E. Condra, E. F. Schramm, A. L. Lugen, *Nebraska Geol. Survey Bull.*, 4, 2d Ser. (1931), and the names of wells are those used in this bulletin. The figures indicate the thicknesses of the systems penetrated, except where the figure is followed by a plus (+) sign which indicates that the bottom of the test was at this point.

* Several other wells in or near Omaha also reach the Mississippian rocks or penetrate into older formations but the records are incomplete or otherwise too inadequate to be included here. This is also true of the deep well at Holdrege, Kansas. Also, a deep well at Holdrege, one at Red Cloud and one at Campbel have been only tentatively determined from the log and a complete set of samples by A. C. Hornady of the Nebraska Geological Survey. The log of this well has not yet been published.

† The drilling at the Morgan well near Salem has penetrated Mississippian, Devonian, Silurian, and Ordovician rocks so far, but the data can not yet be released. The log has been tentatively worked out by A. C. Hornady. Since the preparation of this table and the completion of this manuscript, the "Morgan well" has been abandoned at a depth of about 3,500 feet on a ferruginous sandstone, presumably the top of the Cambrian system.

Devonian systems, while not yet recognized, are not certainly known to be absent in the great Paleozoic basin of central Nebraska (Fig. 1), or west of the Cambridge anticline. These systems may well be present in the basins and low on the flanks of the anticlines and buried ridges; since most of the deep tests have been located on structural and pre-Cambrian "highs," these systems of rock may not have been encountered.

Table V, "Pre-Pennsylvanian Systems of Rock Encountered in Deep Wells in Nebraska," is representative of the thicknesses and known occurrences of the systems under discussion. "Deep Wells of Nebraska" should be consulted for detailed information and logs of these and other deep wells which penetrate the older Paleozoic rocks of the state.

The early Paleozoic seas undoubtedly extended over the pre-Cambrian surface from several directions. The Nemaha ridge projected above the water level and remained a large island or chain of islands until Pennsylvanian time, being more completely inundated during each successive period. There were rejuvenating uplifts from time to time, as explained earlier in this paper (see "Pre-Cambrian, Topographic, and Structural Interpretation"). The Sioux Falls area of pre-Cambrian remained a prominent land mass throughout the Paleozoic era and during much of the Mesozoic era. The Cambridge anticline and the Chadron dome were apparently covered by the Cambrian sea but were elevated above water level afterward and remained islands until Pennsylvanian time, except the Chadron dome, which was covered by the Mississippian sea. This is indicated by the presence of Cambrian rocks (Deadwood or equivalent) in the Norton (Kansas) well, the Watkins well at Cambridge, and the Duthie well near Chadron.¹²

Post-Ordovician uplift occurred at Riverton and near Holdrege, as indicated by the presence of Cambrian and Ordovician formations in the Ohio well at Riverton and in the Trees, Bergman well No. 1, at Holdrege. The Silurian and Devonian systems seem to be absent in both of these wells, but both locations were again covered by the Mississippian sea as indicated in Table V.

The absence of Cambrian materials in the Amerada well at Nehawka, and the absence of all pre-Pennsylvanian formations at Table Rock and Du Bois, is easily understood in the light of what has already been said, since these points were on or near the crest of the

¹² For detailed logs of these wells, see "Deep Wells of Nebraska," pp. 224-27, 228-31, 275-77.

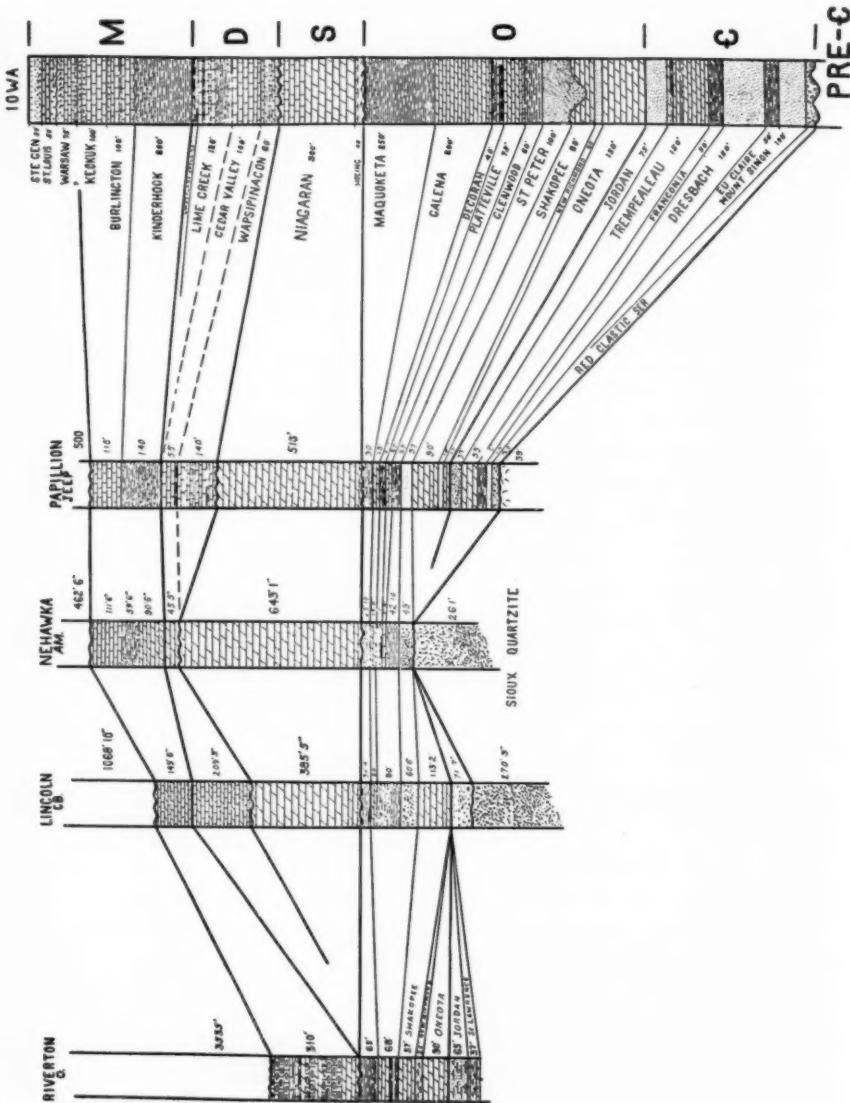


FIG. 3.—Correlation of pre-Pennsylvanian systems in Nebraska and Iowa.

Nemaha ridge. However, the lack of Cambrian deposits, if absent, in the Capitol Beach well at Lincoln is not so easily understood.

It is regrettable that several wells, otherwise good tests, which reached the Mississippian rocks, were not drilled deeper to penetrate older systems, if present, or to the pre-Cambrian. Also, it is unfortunate that better logs and complete suites of samples are not available from a few other wells, which penetrated the older formations and even reached the pre-Cambrian.

The pre-Pennsylvanian Paleozoic section of Nebraska, at least under the eastern part of the state, is almost identical with the early Paleozoic section of Iowa, as exposed in northeastern Iowa and known from deep wells in that state.¹³ Many of the formations are believed to extend continuously from the areas of exposure under Iowa into Nebraska. Most of them are known to thin southwest under Iowa and this fact has been further substantiated by studies in Nebraska. The Silurian system is the only one which thickens in the eastern part of this state. The Cambrian and Ordovician systems, west of the Nemaha ridge, change somewhat in lithology and lose to some extent their identity with Iowa formations, and resemble more the Cambro-Ordovician rocks of Oklahoma (Arbuckle section—Regan sandstone to Sylvan shale interval). The Cambrian sandstone on the Cambridge anticline has been referred by some to the Deadwood formation of the Black Hills. The Deadwood formation is recognized in the Duthie well northeast of Chadron.

Figure 3 represents four Nebraska wells correlated with a generalized Iowa pre-Pennsylvanian section. The Maquoketa-Silurian contact is made a straight horizontal line to facilitate correlation in the figure. The vertical position of the beds in no way indicates structure. However, the figure, drafted in this way, does seem to substantiate the reasonableness of assuming an essentially level St. Peter sea bottom, in eastern Nebraska, as previously mentioned on page 1610. It is thought that sedimentation continued over a nearly level sea bottom until the close of Ordovician time (Maquoketa).

RED CLASTIC SERIES

The "Red Clastic series," which has been reported as occurring widely distributed at the base of the Paleozoic section in Iowa,¹⁴ has been recognized at a few places in Nebraska. It is an arkosic sandstone or conglomerate and is usually more or less red. It usually

¹³ *Iowa Geol. Survey*, Vols. XXI and XXXIII.

¹⁴ W. H. Norton and others, "Underground Water Resources of Iowa," *Iowa Geol. Survey*, Vol. XXI (1912), pp. 70-71.

contrasts rather strikingly with the overlying lighter-colored, cleaner quartz sandstones of the Cambrian, which may be unconformable on it.

The arkosic character of the "Red Clastic series" also contrasts noticeably with overlying sandstones, and this characteristic permits it to be fairly well described by the expression, "Granite wash," sometimes applied to basal materials of almost any age derived by weathering from ancient crystalline rocks. It may be in part a residue of weathering and in part transported and reworked by sub-aerial agencies, when the pre-Cambrian surface was exposed, prior to the upper Cambrian inundation.

* Its age is then problematical. Norton¹⁶ considers that this material may be pre-Cambrian in age, or that it may be middle Cambrian; in any case he seems to think that it is not closely related to the true upper Cambrian marine deposits.

CAMBRIAN SYSTEM

The true Cambrian formations so far identified from Nebraska wells, are thought to be the same as those known in Iowa and have been so correlated. They are all believed to belong to the Croixan series of upper Cambrian age. The Cambrian beds of eastern and southern Nebraska are also thought to be more or less equivalent to the Deadwood formation of the Black Hills, and to the Cambrian deposits of Oklahoma.

It is generally true that the Cambrian subdivisions are more difficult to recognize in Nebraska than in eastern Iowa, the sandstone units are more dolomitic and the dolomite units are more sandy. Differentiation of the individual lithologic units is easier to recognize in the southeastern part of the state, near or east of the Nemaha ridge, than elsewhere. The oldest Cambrian formations, so far recognized in the state, have been found in wells located some distance, usually several miles, from the crest of the ridge and, for the most part, east of it in the "Forest City basin."

The lowest Cambrian formations recognized in Iowa, the Mount Simon sandstone and the Eau Claire formation, have not as yet been recognized here, but even these beds may occur and may yet be identified from deeper drillings low on the flanks east of the "Nemaha Mountains."

Dresbach sandstone.—This formation seems to range from 15 to 64 feet in thickness. It may be even thicker in some places and is entirely absent under large areas. It is made up of rounded to sub-

¹⁶ W. H. Norton, *op. cit.*, pp. 70-71.

angular quartz sand with a little fine admixture. It is usually white-to-light yellow-buff in color, and clean, but may contain some dolomitic cementing material.

St. Lawrence formation.—This formation is made up of a lower member of marly glauconitic shale, containing many fine angular quartz particles known as the Franconia member, and an upper more or less massive dolomite unit known as the Trempealeau dolomite member. Both of these members are thought to have been recognized in the Victor Jeep well near Papillion. Here the Franconia member is 25 feet thick and is a dolomitic marl containing much very fine angular quartz silt, similar to but less pure than the Trempealeau member above. The Trempealeau dolomite member in the Jeep well is 53 feet thick, pure, gray, sparkling dolomite, vesicular and iron stained. The St. Lawrence formation is also believed to have been recognized in the Lane well near Omaha, where it may be 116 feet thick, and in the Ohio well at Riverton, where 37 feet of the formation may have been penetrated at the bottom of the well.

Jordan sandstone.—This formation is believed to have been recognized in the Lane, Jeep, Brick Plant (Nebraska City), and Ohio (Riverton) wells and ranges from 18 to 68 feet thick. As a whole, it consists of fine-to-medium-coarse sand. The grains are usually angular to sub-angular fairly clean clear quartz. In the Jeep well at Papillion the texture is a little coarser than elsewhere and the grains are rounded to subangular. Nearly all parts of the formation are cemented with light gray-to-buff-colored crystalline dolomite. Some zones are more nearly pure dolomite and other zones contain some glauconite. Portions of the formation are more or less ferruginous and somewhat vesicular. In reality the formation is more of a dolomite or dolomitic "grit" than a sandstone.

ORDOVICIAN SYSTEM¹⁶

This system has been identified in ten deep test wells drilled in Nebraska. They are the Miller Park and Lane wells in Douglas County; the Fort Crook, Jeep, and Schuyler wells in Sarpy County; the Nehawka (Amerada) well in Cass County; the Brick Plant well at Nebraska City in Otoe County; the Capitol Beach well in Lancaster County; the Ohio well at Riverton in Franklin County, and the Morgan well near Salem in Richardson County.

The known thickness of the rocks of this system in the state ranges from 154.5 feet in the Nehawka well, where the lower part of the

¹⁶ The writer is indebted to E. C. Reed, graduate student, University of Nebraska, for the tabulation of much of the data on the Ordovician system used in this paper.

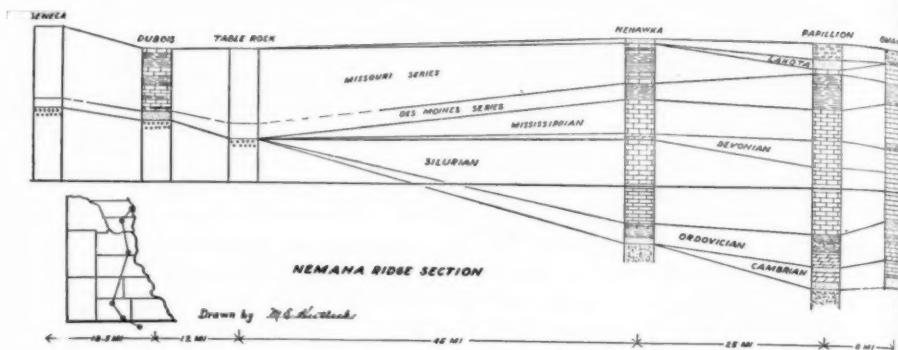


FIG. 4.—Section showing thickening of formations northward over crest of Nemaha ridge.

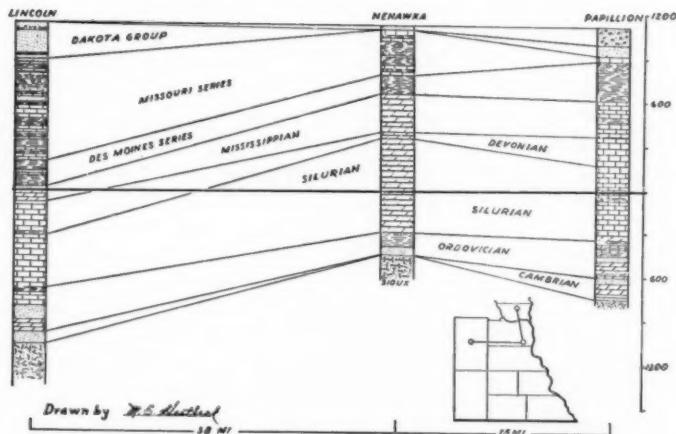


FIG. 5.—Stratigraphy west of and along Nemaha ridge. Nehawka and Papillion are on or nearly on crest of ridge. See also Figure 4.

Ordovician (the Prairie du Chien) is missing and the St. Peter sandstone rests directly on the pre-Cambrian Sioux quartzite, to a maximum of 458 feet at Nebraska City. The average thickness is approximately 281+ feet. The Ordovician thickens northward over the crest of the buried Nemaha ridge from nothing at Du Bois to 154.5 feet at Nehawka, 265 feet at Papillion, and 272 feet in the Lane well near Omaha. This is well shown in Figure 4. Farther north, at Sioux

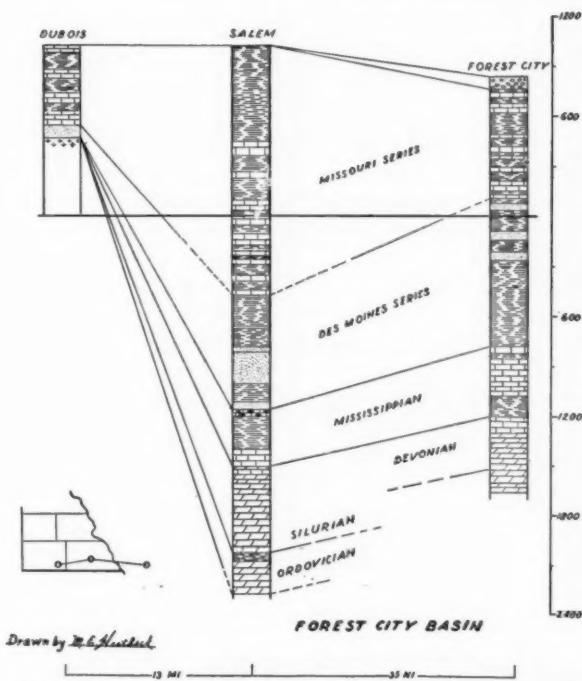


FIG. 6.—Forest City basin east of Nemaha ridge at Du Bois. See also Figure 7.

City, Iowa, there appears to be about 300 feet of Ordovician present, as indicated in Figure 8.

West of the buried Nemaha mountains the section thickens gradually to 308 feet at the Capitol Beach well at Lincoln and 305 feet were penetrated at Riverton. This system thins out to nothing at some point between Riverton and Cambridge. But east of the Nemaha ridge, the system thickens to a maximum of 458 feet at Nebraska City and 340 feet are present in the Fort Crook well and about 400 feet

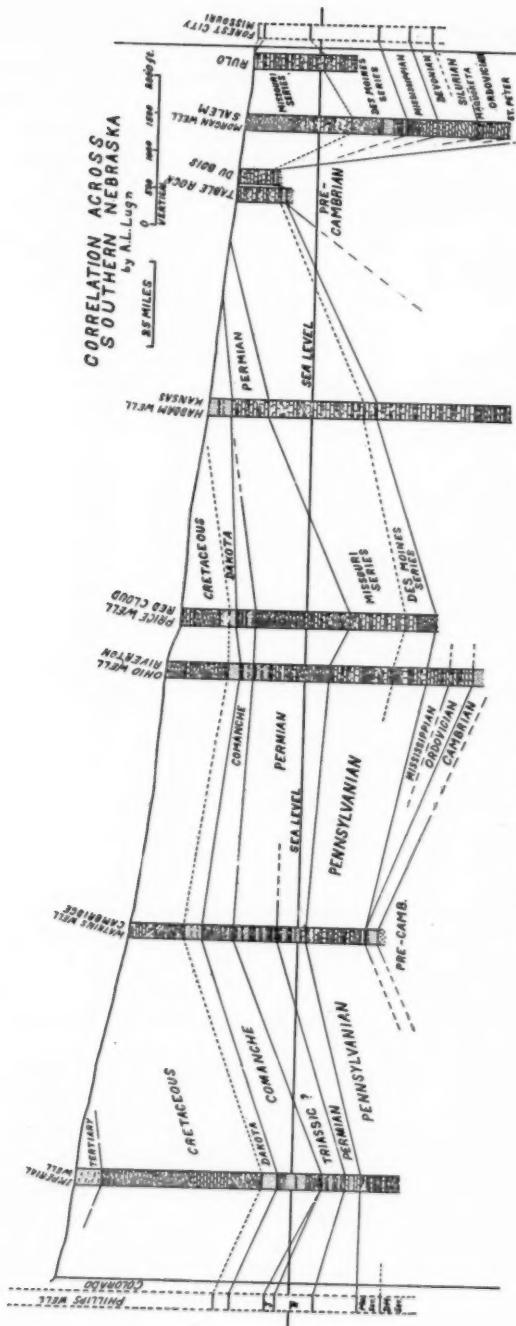


FIG. 7.—Correlation across southern Nebraska. Compare Figure 1.

have so far been encountered in the Morgan well near Salem. These relationships are shown in Figures 2, 3, 4, 5, 6, and 7. Ordovician rocks may be expected, at depth, under at least the southeastern third of the state, with the exception of a small narrow area along the crest of the buried Nemaha mountains.

The Prairie du Chien group is made up of the Oneota, New Richmond, and Shakopee formations and is the older lower magnesian "series" in contrast to the Platteville-Galena, the old upper magnesian "series" of the earlier literature. The Prairie du Chien group is no doubt equivalent to the upper part of the Arbuckle limestone of Oklahoma.

Oneota dolomite.—This formation ranges from 8 to 90 feet in thickness, but is generally thin, averaging not much more than 10-20 feet. The thickness of 90 feet, in the Ohio well at Riverton, may be too great or else it indicates a rather unusual local development. It is generally white or light gray-to-buff, somewhat vesicular, very pure crystalline sparkling dolomite. The cleavage fragments of the sparkling white dolomite are often mistaken for "sand" by drillers. The formation contains thin "seams" or partings of dark red, greenish, or dark gray-to-black shale. Angular fine quartz grains are found in some zones.

New Richmond sandstone.—This formation is much like the underlying Cambrian sandstones described earlier in this paper. It ranges from 12 to 42 feet in thickness and averages about 15 feet. It is really a dolomitic "grit" with many fragments of fine angular quartz or sand. Where it is very dolomitic, it is white-to-buff, crystalline, more or less ferruginous, pyritic, with thin partings of reddish, dull green-to-black shale. It almost everywhere contains angular quartz grains in greater quantity than the Oneota below or the Shakopee formation above. It is a "sandstone" only by comparison with the purer dolomites above and below it.

Shakopee dolomite.—This formation ranges in thickness from 57-155 feet and averages about 90 feet. It is a massive pure dolomite, white-to-buff in color, crystalline, slightly ferruginous, more or less vesicular, contains zones and thin partings of shale, usually green but in places red-to-black. Its cleavage fragments are sparkling and white, sometimes ferruginous, and like the fragments of the Oneota are sometimes mistaken for "sand" by drillers. In some places certain zones contain angular grains of fine quartz sand, but it is usually not "sandy."

St. Peter sandstone.—The formation of the Shakopee dolomite, the upper member of the Prairie du Chien group, was followed by

uplift and general and widespread sub-aerial erosion. One of the most important unconformities of the lower Paleozoic occurs at this point. Trowbridge¹⁷ has described the development and the magnitude of this Prairie du Chien-St. Peter unconformity and has shown that the relief on the Prairie du Chien is as much as, or more than, 150 feet in northeastern Iowa. Trowbridge also pointed out the existence of two phases of the St. Peter formation: a valley phase and an upland phase. The existence of these two phases and the unconformable relation of the St. Peter sandstone to the dolomite below in Nebraska are both supported by evidence from several deep test wells.

The St. Peter formation has been recognized and differentiated with reasonable certainty in eight deep wells in Nebraska: the Miller Park, Lane, Jeep, Schuyler, Nehawka (Amerada), Nebraska City, Capitol Beach, Trees Bergman No. 1 (Holdrege) wells. It has been penetrated also in the Fort Crook and Riverton wells, but has not been differentiated.

The valley phase of the formation is thought to have been recognized in the Amerada well at Nehawka (7 feet only), the Schuyler well at Papillion (the lower 22 feet), and perhaps the lower 20-30 feet of the formation in the Capitol Beach well at Lincoln may belong to the valley phase. This phase consists of interbedded conglomerate, shale, and sandstone layers, thin for the most part. The conglomerate layers consist of dark pebbles in gray sand; the shale is also gray. Oboloid brachiopod fragments are fairly abundant.

The formation as a whole ranges from 12 feet thick in the Lane well to 61 feet in the Schuyler well near Papillion. Its thickness averages about 45 feet. The upland phase is quite uniform in lithology, continuous and extensive in its occurrence. It is thought to have been recognized in a layer of sub-rounded, moderately fine, frosted quartz sand, in the Trees Bergman well No. 1 at Holdrege, at a depth of about 4,390 feet below the surface. The thickness of the bed is unknown as samples were preserved from only 9 feet, from a depth of 4,386 to 4,395. The St. Peter sandstone is usually clean, light gray-to-almost white, fine-textured, well rounded and even frosted, quartz sand grains. It is usually more well rounded and finer in texture than the Cambrian sandstones and is generally friable and not cemented with dolomite. The St. Peter formation is not sharply differentiated from the overlying sandy shale, the Glenwood, into which it seems to grade.

The St. Peter formation of Iowa, Missouri, and Nebraska is

¹⁷ A. C. Trowbridge, "The Prairie du Chien-St. Peter Unconformity in Iowa," *Proc. Iowa Academy of Science*, Vol. 24 (1917), pp. 177-82.

thought to be equivalent to one or more of the so-called "Wilcox" sand horizons of the Simpson formation of Oklahoma.

Glenwood shale.¹⁸—This formation is recognized as a distinct stratigraphic unit by the Iowa State Geological Survey, but most geologists and other State surveys usually regard it as the lower part of the Platteville formation. It has been differentiated in the Lane, Jeep, and Amerada wells in Nebraska and has been recognized but not differentiated in several others. Where differentiated, it ranges from 16 to 43 feet in thickness and consists of hard, dark greenish shale with selenite crystals and dark thin gray limestone layers, some sandstone seams, more sandy in the lower part. The Glenwood beds are transitional between the St. Peter sandstone and the Platteville limestone. The Glenwood and the Decorah shales are much alike, but both differ from the Maquoketa shale in being harder, and typically brighter green, at least greenish, whereas the Maquoketa is usually bluish gray or bluish green in color.

The Glenwood shale has yielded fragments of "flattish ramosed bryozoa," *Rafinesquina* sp., *Dalmanella* sp., and *Pinonodema subaequata* from the core of the Amerada well.¹⁹

Platteville limestone.—This formation is generally included with the Glenwood and Decorah shales in most logs. It has been differentiated in the Lane, Jeep, and Amerada wells. It consists of 20 feet of "earthy blue and gray dolomitic limestone, massive, with some shaly partings" in the Jeep well at Papillion. It is 7 feet thick in the Schuyler well, also near Papillion, and is an "earthy blue and gray, argillaceous, dense limestone." The "Platteville limestone, brownish, fine grained, dense, conchooidal fracture," is said to be very typical in the core of the Amerada (Nehawka) well. It is 7 feet 2 inches thick in this core and has yielded *Rafinesquina* sp., and *Trematis ottawaensis*.

Decorah shale.—This formation includes all shale and calcareous beds between the Platteville and Galena formations. It has been recognized in the Lane, Jeep, Schuyler, Amerada (Nehawka) wells, and possibly in the Nebraska City (Brick Plant) well. It is usually about 20 feet thick and consists of a lower shale, the Spects Ferry member, a middle gray and argillaceous limestone, the Guttenberg

¹⁸ W. H. Norton and others, "Underground Water Resources of Iowa," *Iowa Geol. Survey*, Vol. XXI (1912), pp. 83-84. Also, *U. S. Geol. Survey Water-Supply Paper* 293, pp. 73-74. Also, "Deep Wells of Iowa," *Iowa Geol. Survey*, Vol. XXXIII (1928), pp. 33-36.

¹⁹ "Deep Wells of Nebraska," pp. 71-86.

member, and an upper dark sandy shale, the Ion member.²⁰ The Decorah beds are commonly distinctly dark green and greatly resemble the Glenwood shale. In fact, the beds above the St. Peter sandstone to and sometimes including the Galena dolomite, are interpretable in more than one way. According to one interpretation the Decorah formation is only 17 feet thick in the Amerada core, but it can be otherwise interpreted to include other horizons, in which case it can be regarded as being 33 feet, 6 inches, thick in the same core. The writer favors the first interpretation, but has stated the basis for the validity of the second interpretation.²¹

The upper shale member has yielded the following fossils from the Amerada core: fragments of ramosc bryozoa, *Rhinidictya* sp., *Homotrypa* sp., *Monticulipora* sp., *Rafinesquina* sp., *Rhynchotrema* sp., *Plectambonites* sp., *Zygospira recurvirostris*.

Galena dolomite.—The Galena formation is a distinctive lithologic unit of most well logs. It is usually recognized and is easily identified. It has been differentiated in the following wells in Nebraska: Miller Park, Lane, Fort Crook (?), Jeep, Schuyler, Amerada (Nehawka), and Nebraska City (Brick Plant). It is believed that it will be differentiated in the Trees Bergman well No. 1 at Holdrege and that it will be found to be unusually thick in the Morgan well near Salem. It was no doubt penetrated in the Ohio (Riverton) well, but has not been definitely differentiated in the log.

The Galena formation is a grayish white-to-buff-colored, hard, finely crystalline, sparkling dolomite and magnesian limestone. It is more or less vesicular, and contains some chert and pyrite. It may include thin partings of greenish, hard calcareous shale. From data so far available, it ranges in thickness from 15 to 35 feet, averaging about 22 feet.

Maquoketa shale.—This shale is one of the most distinctive and easily recognized formations in the entire lower Paleozoic section under Nebraska. Its thickness ranges from 20 feet to 113 feet and averages about 38 feet. However, about 60 feet is regarded as a more normal thickness. It is thin (20–30 feet), over the crest of the Nemaha ridge and thickens (60–113 feet), on the flanks of the ridge and in the basins. It has been recognized and differentiated in 10 deep wells in the state. It is bluish gray shale, calcareous, massive, somewhat

²⁰ G. Marshall Kay, "Stratigraphy of the Decorah Formation," *Jour. Geol.*, Vol. XXXVII (October–November, 1929), pp. 630–71. Also, G. Marshall Kay, "Correlatives of Mohawkian Sediments in Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 9 (September, 1929), pp. 1213–14.

²¹ See statement by the writer in "Deep Wells of Nebraska," p. 86. The Nehawka (Amerada) well, pp. 71–86.

pyritic, and in very small fragments appears bluish green or greenish under magnification, especially with transmitted light. In bulk it is usually bluish gray in color but may be greenish. It contains thin dolomitic layers in some places. The Maquoketa shale is thought to be the exact equivalent of the Sylvan shale of Oklahoma.

This formation yielded: *Isotelus* sp., *Plectambonites sericeus*, *Dalmanella* sp., from the Amerada (Nehawka) core. At Riverton, the Maquoketa shale was found to be 65 feet thick in the Ohio well²² and the middle and lower parts yielded the following fossils: *Diplograptus*, *Climacograptus*, *Hormotoma*, *Homotrypa*, *Liospira*, *Rhinidictya*, chondrites, fish bones and plates. The writer²³ has stated the following regarding the probable age of the Maquoketa beds in Nebraska.

The fossils so far found in the Maquoketa are suggestive of the lower part of this formation. *Diplograptus* and *Climacograptus* are known from the Elgin beds.* The genus *Homotrypa* is known from somewhat higher horizons and some species of it are known from beds as low as the Ion member of the Decorah. The genera *Liospira* and *Rhinidictya* are common in the basal Maquoketa beds* and have a fairly wide vertical range.

* H. S. Ladd, "The Stratigraphy and Paleontology of the Maquoketa Shale of Iowa," *Iowa Geol. Survey*, Vol. XXXIV (1929), pp. 305-448.

This paleontological evidence strongly supports the idea that the Maquoketa under Nebraska is the lower part of the formation. This conclusion is corroborated by the fact stated previously that the formation is thin (20-30 feet) over or near the crest of the Nemaha ridge and thicker (60-113 feet) low on the flanks of the ridge or in the basins. Apparently the post-Ordovician diastrophism elevated Nebraska above sea-level and also effected differential movement between the ridges or "highs" and the basins. The upper or younger beds of the formation have been removed by erosion. This is strictly in agreement with the known facts of late or post-Ordovician history throughout the entire North American continent.

It is thought that if any Ordovician strata were deposited across the Cambridge anticline or on the Chadron dome, it may have been completely removed by erosion as a result of differential uplift at this time.²⁴ Also anticlinal structures or other "highs" may have been raised sufficiently above the basins at this time so that no Silurian or Devonian strata ever came to be deposited over such structures as the Cambridge anticline, the Chadron dome, or at Riverton or Holdrege, where the Mississippian strata rest on the Maquoketa shale.²⁵

²² "Deep Wells of Nebraska," pp. 187-215.

²³ *Ibid.*, p. 215.

²⁴ *Ibid.*, pp. 228-31, 275-77.

²⁵ *Ibid.*, pp. 209-11.

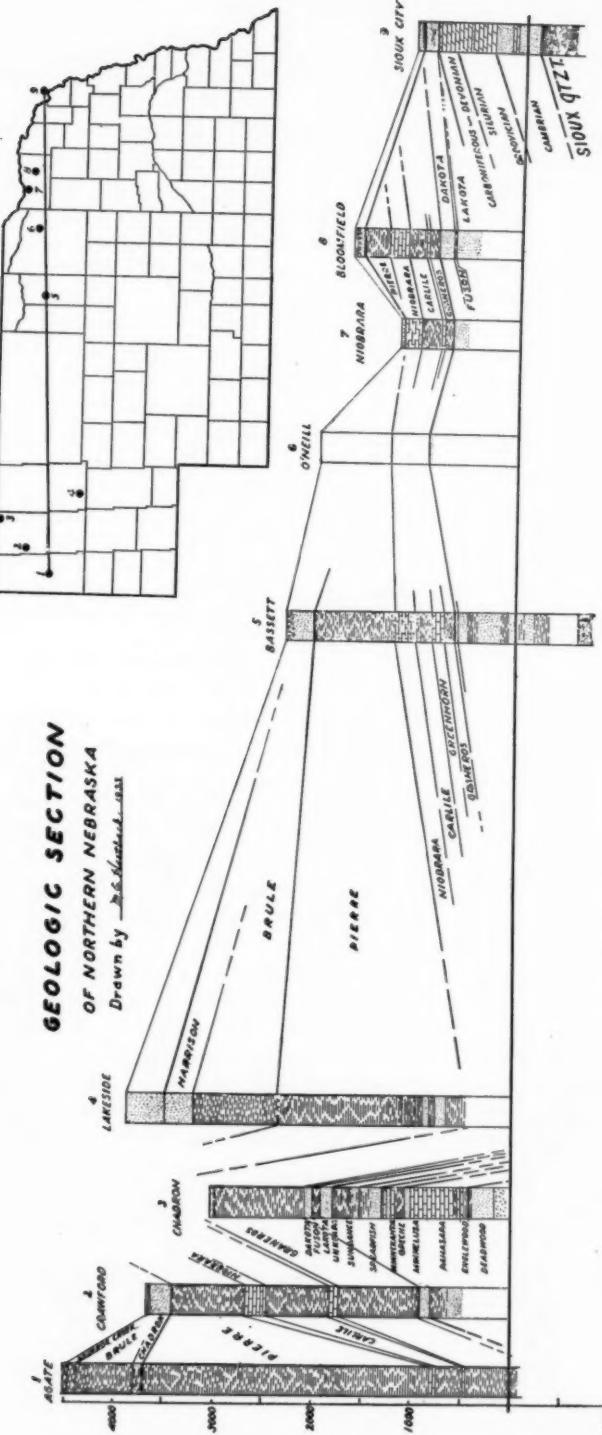


FIG. 8.—Stratigraphic relationships of formations across northern Nebraska.

SILURIAN SYSTEM

The Silurian strata so far known in Nebraska seem to be continuous with and equivalent to the rocks of the same system in Iowa and are so correlated. In age, they are middle Silurian or Niagaran. Accordingly, a very great regional erosional unconformity occurs below the Silurian strata and they rest unconformably on the eroded Maquoketa shale or older formations. The thickness of the Silurian system in Nebraska is great but also irregular, probably because of the irregularity and unevenness of the surface over which the Niagaran sea advanced.

Rocks of Silurian age have been recognized in 12 wells used in this report, all located in the eastern and southeastern part of the state, except the Forest City well in Missouri. Silurian strata have also been recognized in a deep well at Sioux City, Iowa, shown in Figure 8. The minimum complete thickness so far reported in Nebraska is 190 feet in the Miller Park well at Omaha, and the maximum complete thickness is 643 feet, 1 inch, from the core of the Amerada well at Nehawka. The average thickness is about 427 feet.

It is an interesting point that the maximum thickness, at Nehawka, is on or near the crest of the Nemaha ridge. Apparently the pre-Silurian peneplanation, at least in its later stages, was not influenced by the buried "granite" or pre-Cambrian ridge at or near Nehawka. However, the ridge seems to have been well above sea level in the vicinity of Du Bois and Table Rock during the Silurian inundation. The presence of Silurian strata in western Nebraska and in the great central basin has not been demonstrated, but on the other hand the absence of Silurian strata has not been proved.

The Silurian under eastern Nebraska consists almost entirely of light gray-to-bluish gray and in part brownish or buff-colored dolomite. Some chert and soft white tripolite-like siliceous material has been noted near the middle of the system. A very little bluish gray shale has been noted at some places and a little sandstone also in some wells. The dolomite is for the most part massive and heavily bedded. It is known to contain such characteristic Silurian fossils as: *Favosites favosus*, *F. niagarensis*, *Halysites catenulatus*, and *Conchidium occidentalis*.

Since no upper Silurian rocks seem to occur under even eastern Nebraska, and all of the Devonian system, except upper Devonian strata, is absent also, uplift and a long period of subaerial erosion seems to have followed the deposition of the Niagaran strata.

DEVONIAN SYSTEM

All of the strata which have been correlated as Devonian in Nebraska apparently occur under only the eastern part of the state. The distribution seems to be about the same as for the Silurian beds, on which the Devonian rocks rest with great unconformity. There is no record so far of Devonian strata overlapping the Silurian and resting on older beds. As in the case of the Silurian system, the presence of Devonian rocks has not been demonstrated in western or central Nebraska, nor has the absence of Devonian strata been proved. The presumption is strong that Devonian rocks are absent except in the eastern part of the state, since there are no Devonian formations in the Black Hills, Laramie and Hartville areas in Wyoming, in north-central Colorado (?), in the deep wells of northwestern Kansas, or in south-central Nebraska.

The Devonian rocks consist mostly of very white-to-gray limestone or dolomitic limestone. A relatively thin bed of gray or greenish shale occurs commonly at the base and grayish or bluish shale layers may be encountered at other levels. The limestone is argillaceous and in part even glauconitic in some zones. Pyrite also occurs in places. The thickness ranges from 45 feet, 5 inches (or less?), to more than 200 feet in Nebraska. The average for the area under consideration is about 160 feet.

Almost nothing has been done to correlate exactly the Devonian beds in Nebraska. The 195 feet of Devonian found in the Jeep well²⁶ near Papillion is at least suggestive of the Wapsipinicon and perhaps the Cedar Valley divisions of the Devonian of Iowa.

MISSISSIPPIAN SYSTEM

Rocks belonging to the Mississippian system are now known to occur under essentially the entire state. Stratigraphically, the Mississippian strata may or may not be unconformable on the Devonian, but the evidence is somewhat in favor of an unconformable interpretation. No Mississippian strata were deposited over the Nemaha ridge in the vicinity of Du Bois and Table Rock, which indicates that this part of the ridge was still an island or group of islands in the Paleozoic (Mississippian) sea. The Mississippian formations naturally overlap extensively on the older formations and systems of rock, even Ordovician and Cambrian, as at Riverton, Hol dredge, and Chadron.²⁷

²⁶ "Deep Wells of Nebraska," pp. 64-68.

²⁷ *Ibid.*, pp. 187-215, 275-77.

Detailed correlations of the Mississippian strata of the state have not been made, but it seems quite certain that formations belonging to the Kinderhook and Osage groups are present. It is doubtful if beds of St. Louis age occur extensively, if at all, in the state, even though they are supposed to have been recognized in the core of the well at Forest City, Missouri.²⁸

Mississippian strata range from about 110 feet to more than 400 feet in thickness. The average thickness is nearly 300 feet and the thickness of this system is more uniform than that of either the Devonian or Silurian systems in the state.

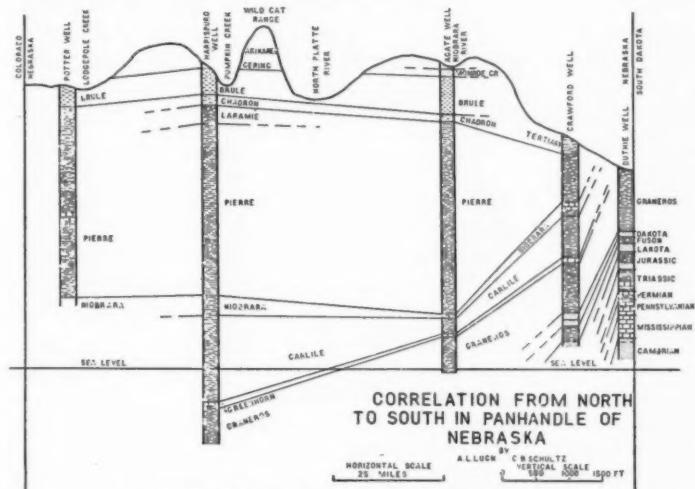


FIG. 9.—Geologic profile section across western Nebraska.

Cherty limestone, with beds of chert and brownish dolomitic limestone, are characteristic of the Osage formations of the system, especially in the south-central part of the state. The same beds seem to have less chert farther east. Partings and thin beds of greenish shale are also common. The Kinderhook group is represented by buff-gray, crystalline, dense and fine-grained rather massive limestone and, at least in some wells, by heavy bluish gray "mouse-colored" calcareous shale. The Kinderhook shales are the most distinctive strata in the section above the Maquoketa shale.

The Mississippian system is represented in northwestern Nebraska

²⁸ H. Hinds and F. C. Green, "The Stratigraphy of the Pennsylvanian Series in Missouri," *Missouri Geol. Survey*, Vol. XIII, Second Ser., pp. 215-39.

by the Pahasapa limestone (356 feet) and the Englewood formation (45 feet), which lies in contact with the Deadwood formation of Cambrian age.²⁹ The Pahasapa limestone is crystalline grayish white-to-white with some buff-colored zones and a very little gray shale. The Englewood formation consists of limestone, some reddish shale and a little sandstone. These formations are indicated in the Duthie well section in Figure 8. They are also represented in Figure 9, which indicates the general stratigraphic relations from north to south across western Nebraska.

The Mississippian period closed with general uplift followed by erosion. The surface was dissected by drainage, and a mature topography resulted that is believed to have had a relief of at least 200-250 feet in eastern Nebraska, as it is known to have had in south-central Iowa.³⁰ Hence, the Pennsylvanian deposits came to be unevenly and unconformably laid down on a very irregular surface.

CONCLUSIONS

It should be evident to the reader, in view of the brief and somewhat inconclusive evidence here presented, that very little is really known about the subsurface geology and stratigraphy of Nebraska. A number of excellent and reliable logs of carefully made deep-test wells have been preserved and are available, but it is preposterous to claim that the state has been adequately "tested" both as to the possibilities for oil and gas and for structure and stratigraphy in the deeply buried strata. More "dry" holes have been drilled locally in many oil-producing areas than have so far been drilled into the lower Paleozoic strata in the whole state of Nebraska. However, there is no gainsaying the fact, that so far there has been no very encouraging evidence that oil or gas exists in Nebraska in even modest quantities.

Every Paleozoic system below the Pennsylvanian is represented by identifiable rocks in the subsurface section of Nebraska, and is present at least east of the buried Nemaha ridge. The exact subsurface distribution of each of the Paleozoic systems is not yet known with certainty. Apparently all formations are the same as, and continuous with, the pre-Pennsylvanian rocks of Iowa. The Cambrian and Ordovician rocks, and perhaps also the Mississippian of the southern part of the state, are also similar to correlative formations in Oklahoma. The fact that most of the deep-test wells so far drilled in the state

²⁹ "Deep Wells of Nebraska," pp. 275-77.

³⁰ A. L. Lugh, "The Mississippian-Pennsylvanian and Pennsylvanian-Pliestocene Unconformities in Lucas County, Iowa," *Proc. Iowa Academy of Science*, Vol. XXXII (1925), pp. 351-56.

have been located on structural or on monadnock-like pre-Cambrian "highs" has precluded the discovery of many pre-Pennsylvanian Paleozoic rocks, which occur in the "basins." This has led to the misconception that Nebraska was not invaded by all of the Paleozoic inundations.

Sioux quartzite, granite, and schistose metamorphic rocks have been recognized in the pre-Cambrian. The present irregularities, the "basins and highs," on the pre-Cambrian surface are the result of erosion and a long structural history. In general, successively younger rocks rest unconformably by overlap against the pre-Cambrian "highs." The principal erosional and structural "highs" are the "Nemaha mountains," the Cambridge anticline, the Chadron dome, and the Sioux Falls area. "Basins," or saddle-like depressions, occur on the pre-Cambrian surface between the "highs." The largest of these trends from southeast to northwest across the central parts of Nebraska. The history of each ridge or "high" is more or less individualistic, but it seems certain that the structural framework of Nebraska came into existence in late pre-Cambrian time and has dominated the structural and depositional history of the state ever since.

NOTE: Since the writing of all but the last few pages of this manuscript, the excellent and very thorough paper, dealing with most of the stratigraphic problems of the lower Paleozoic systems of the Upper Mississippi Valley, by A. C. Trowbridge and G. I. Atwater,²¹ has come from the press. This is a most excellent paper and several of the problems discussed have important bearings on correlations and interpretations of the pre-Pennsylvanian Paleozoic strata of Nebraska.

²¹ A. C. Trowbridge and G. I. Atwater, "Stratigraphic Problems in the Upper Mississippi Valley," *Bull. Geol. Soc. America*, Vol. 45 (Feb. 28, 1934), pp. 21-80.

ESPERSON DOME, LIBERTY COUNTY, TEXAS¹

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ABSTRACT

The Esperson dome is one of the early deep-seated salt domes discovered as a direct result of geophysical work. In 1928 it was found by torsion-balance exploration. In 1929 oil was discovered. Prior to March 1, 1934, forty-three wells were completed, including thirty-five oil wells. Seven producing horizons are in the Miocene and Oligocene formations. This dome is peculiar in that the salt mass has been thrust upward at an inclined angle leaning north of the vertical position. The crest formed by the arching of the beds above the salt mass moves horizontally with depth.

LOCATION

The Esperson dome, one of the early domes of the deep-seated type discovered as a direct result of geophysical work, is in the province commonly called the salt-dome area of the Gulf Coast. It is located in Liberty County about 30 miles east of Houston, being about 1 mile south of the Beaumont-Houston Highway and about the same distance east of Cedar Bayou, which is the west boundary of the county. Dayton, 4 miles away, is the nearest town.

The neighboring oil fields in this area occur on piercement-type, or shallow, salt domes. Barbers Hill dome is 6 miles southeast, South Liberty dome is 7 miles northeast, and North Dayton dome is 7 miles northwest.

PHYSIOGRAPHY

The topography of the Esperson dome is typical of the Gulf Coastal Plain. The terrane is almost flat, sloping southward and dipping about 2 feet per mile. The significance of the topography is the absence of any surface expression indicating the presence of a salt dome.

HISTORY

Christian Iden, employed by the Union Exploration Company in 1928, located and mapped the Esperson dome prospect as a result

¹ Manuscript received, May 18, 1934.

^{2,3} Goldston and Stevens, geologists, 404 Sterling Building. The writers wish to acknowledge their indebtedness to the management of the General Crude Oil Company for permission to publish this paper, to the paleontological department of the Sun Oil Company for interpretation of all cores and samples recovered from wells drilled in this field, to Christian Iden for permission to publish the original torsion-balance map, and to A. N. Wilson for drafting all maps and charts accompanying this paper.

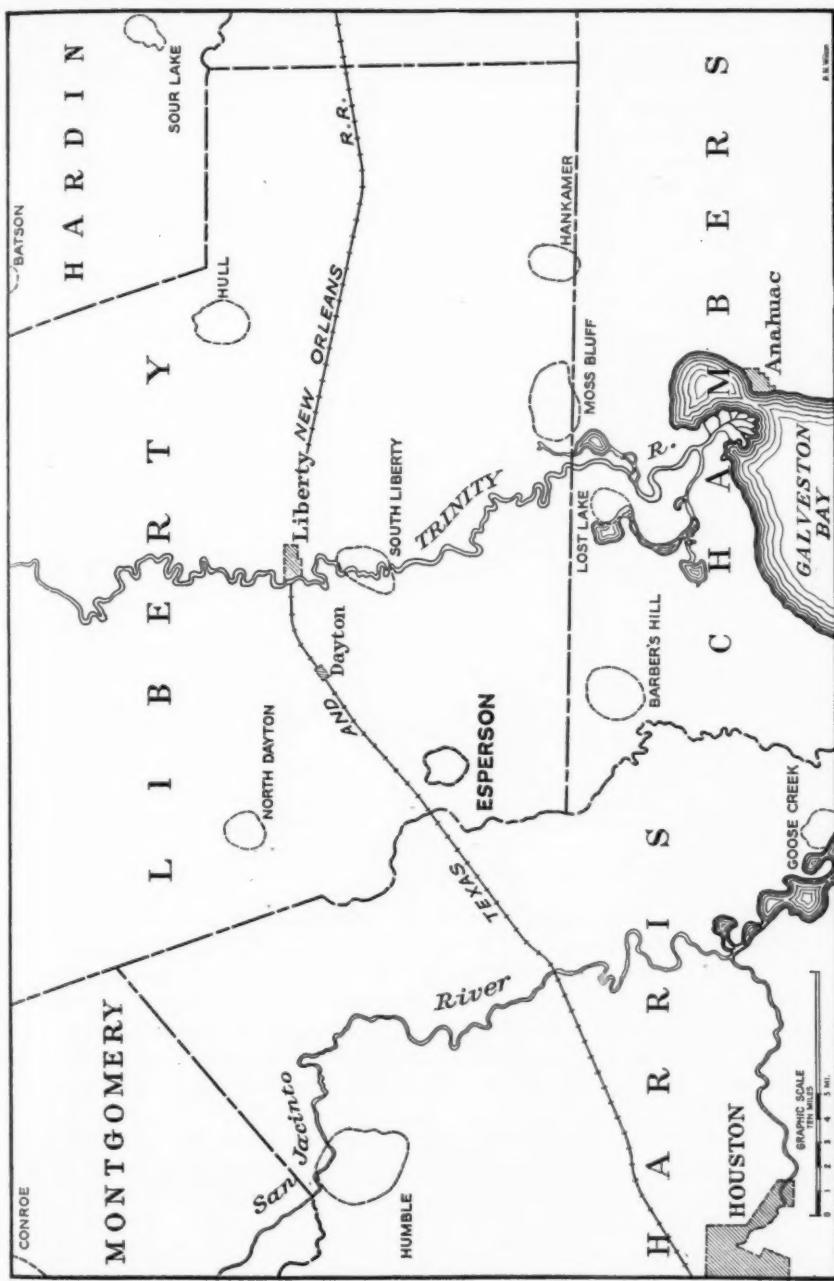


FIG. 1.—Map showing location of Esperson dome and its relation to surrounding area.

of a torsion-balance survey of the Esperson lands in Liberty County. This survey showed twin domes about 3 miles apart. The west dome was the more prominent.

The Union Exploration Company drilled Esperson No. 1 on the west dome to a depth of 5,795 feet and abandoned it as a dry hole, January 8, 1929. No showing of oil was found. Mrs. Paul Applin, however, reported this well to have reached the top of the Yegua near the bottom of the hole. Encouraged by the depth at which the formations were found in this hole, the Union Exploration Company

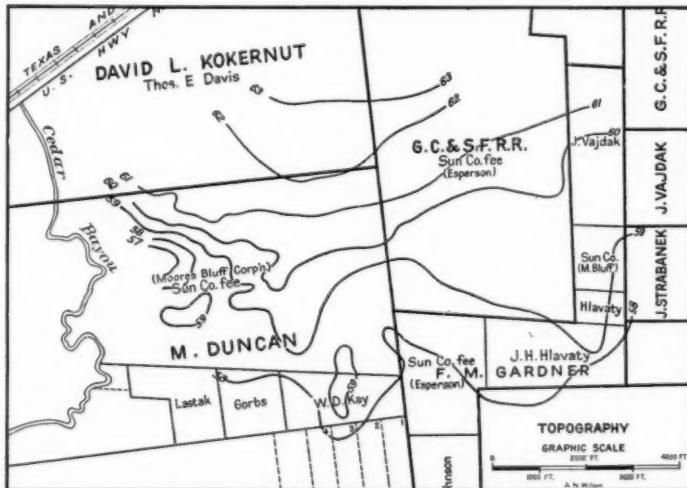


FIG. 2.—Topographic map of part of Esperson dome area. Prepared by engineering department of Cranfill-Reynolds Company.

drilled their Esperson No. 2 about 2,500 feet north and a little west of the first dry hole. This well also was dry, and was abandoned, May 12, 1929, at the total depth of 6,014 feet. However, many Miocene and Oligocene sand horizons saturated with oil were penetrated by this well. On drill-stem tests, a few of these sands showed free oil with salt water. Correlation of the sands showed them to be apparently 200 feet higher in No. 2 than the corresponding sands occurred in the No. 1 dry hole.

As a result of the oil showing in Esperson No. 2, Harvey Smith, independent operator, obtained a lease on a 34-acre tract about 3,000 feet northeast of the Union Exploration Company's No. 2 and began drilling.

ESPERSON DOME, LIBERTY COUNTY, TEXAS 1635

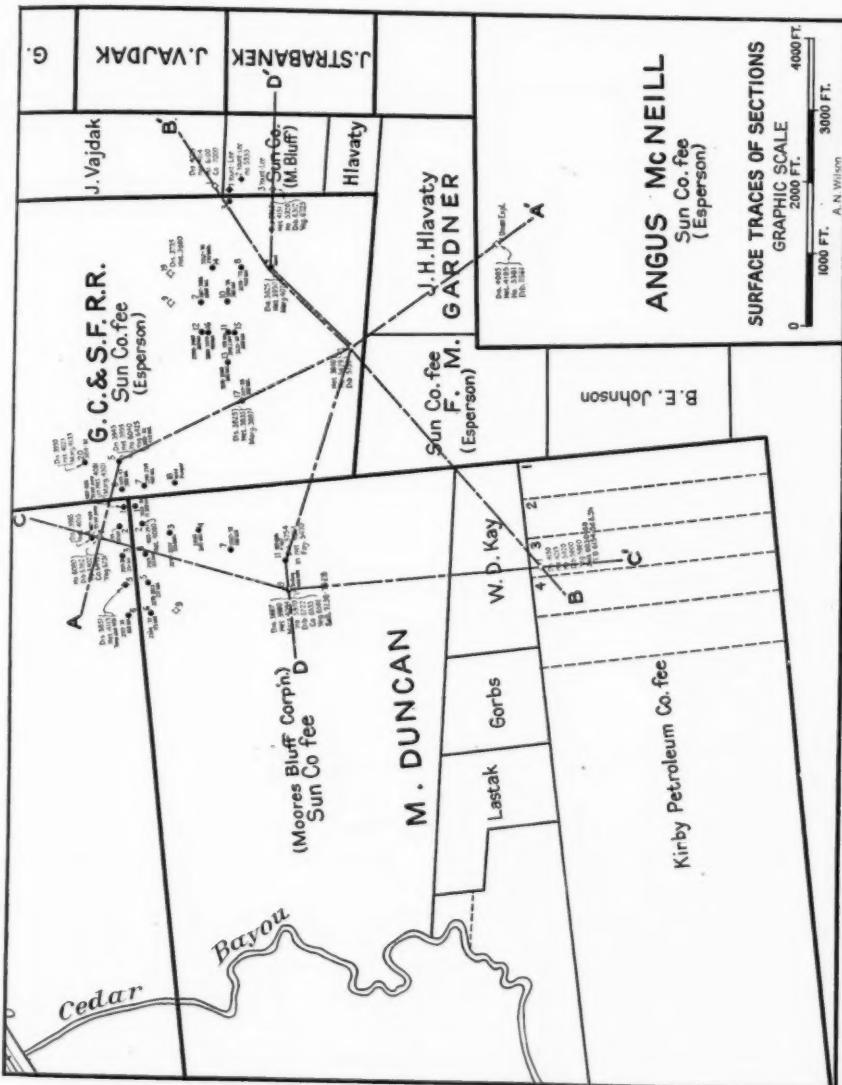


FIG. 3.—Map showing location of oil wells and dry holes, Esperson dome. Total depth and initial production shown for each well.

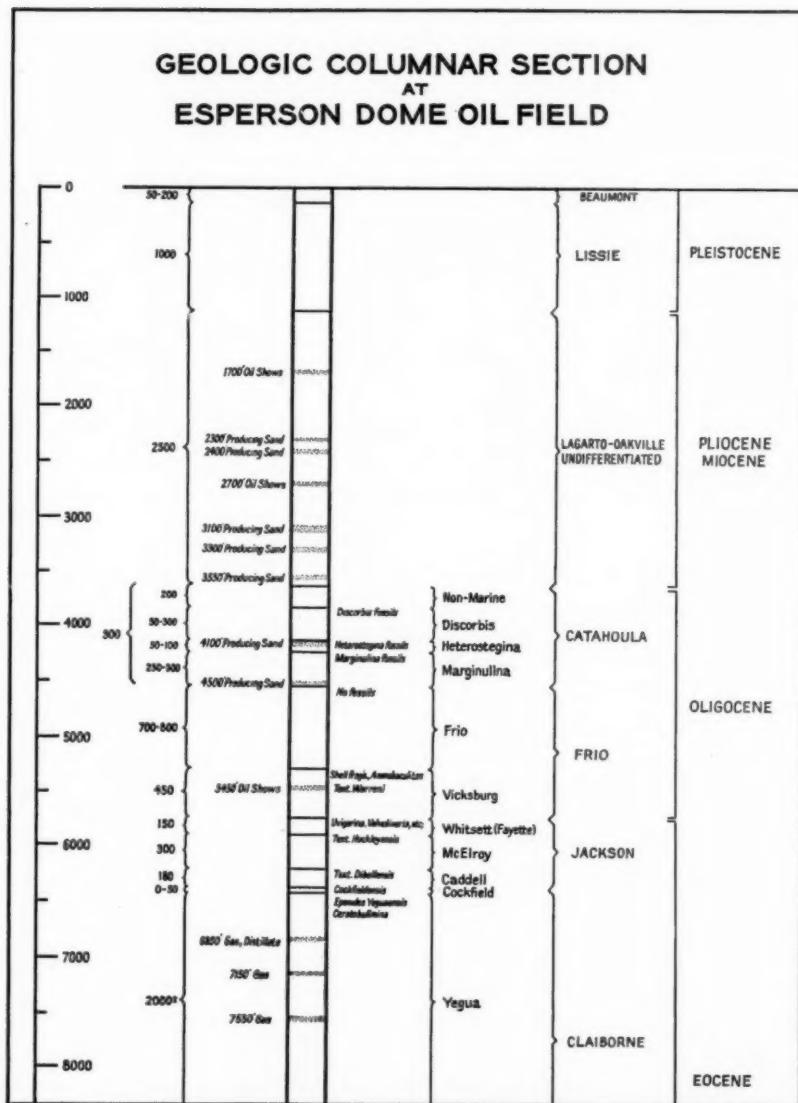


FIG. 4.—Type columnar section, Esperson dome, determined from wells.

ESPERSON DOME, LIBERTY COUNTY, TEXAS 1637

In the meantime, the Cranfill-Reynolds Company acquired the Esperson properties of the Union Exploration Company and began drilling Esperson No. 2-A, about 1,500 feet west and a little north of the Harvey Smith location.

In August, 1929, Harvey Smith completed his well as the first oil well on the Esperson dome. It produced about 800 barrels daily from a sand at 3,306 feet. On September 9, 1929, the Cranfill-Reynolds Company completed its Esperson No. 2-A, producing 90 barrels daily, at a depth of 2,276 feet.

Harvey Smith sold the discovery well and the 34-acre lease to the Yount-Lee Oil Company. Three additional wells were drilled on this property, but it was proved to be an east-edge lease and was abandoned in 1931.

Since abandonment of the Yount-Lee lease, the Cranfill-Reynolds Company has been the sole operator in the field. This company has drilled 38 wells. Of this number, 32 were completed as oil wells and 2 as dry holes, and 4 deep wells were lost as a result of encountering gas in the Yegua sands.

SURFACE GEOLOGY

The surface beds at the Esperson dome belong to the basal members of the Beaumont clays. The nature of these clays and the topography of the area conceal any surface expression of structure that may be present. The Beaumont-Lissie contact is only a few miles north of the Esperson dome. The uplift of the surface beds, if any, is insufficient to bring the Lissie beds to the surface.

STRATIGRAPHY

The Beaumont clays are on the surface. This formation varies in thickness from a few feet to 200 feet. The first sands encountered represent the base of these clays or the top of the Lissie formation.

The Lissie formation consists chiefly of sands and sandy shales intermingled with clays. The sands in this formation are water-bearing, usually fresh water. The formation is approximately 1,000 feet thick. The first appearance of calcareous nodules and cementation in the sandstones and the first appearance of reworked Cretaceous *Foraminifera* in the clays represent the top of the Lagarto formation.

Lithologically, the Lagarto and Oakville formations are very similar. For this reason, in this paper the two formations are considered as a unit. The Lagarto and Oakville group is about 2,500 feet thick and consists of sands, sandy shales, shales, and clays. The sand members are less prominent than those found in the Lissie

formation above. Water in sands is generally salty. In this group five sand members produce oil in the Esperson field: the 2,300-, 2,400-, 3,100-, 3,300-, and 3,500-foot sands. Sandy zones at 2,700 and 2,900 feet also show oil.

The Catahoula formation contains the first paleontological markers. The top of the formation is placed at the top of a 200-foot sand section, near the base of which occur the first *Discorbis* fossils. The *Discorbis* zone ranges in thickness from a few feet to 300 feet. The *Heterostigina* zone varies from 50-100 feet in thickness. The top of this zone is represented by a 2-foot limestone member, although in some wells it is missing. The *Marginulina* zone, which can not be determined lithologically, ranges in thickness from 200 to 300 feet. The base of this zone represents the top of the Frio. The 4,100- and 4,500-foot sands occur in the *Marginulina* zone of the Catahoula formation. Showings of oil are also found in the *Discorbis* member of the formation at approximately 3,800 feet.

On the Esperson dome the Frio beds are considerably thinner than their normal thickness. On top of the structure they are approximately 700-800 feet thick. They consist of sands, shales, and sandy shales. The shales are gray and are easily distinguished from the black and blue shales of the Vicksburg. No producing sands occur in the Frio. However, good showings of oil are found at 4,600 and at 5,000 feet.

Lithologically, with the exception of the Claiborne-Jackson contact, the top of the Vicksburg is the most clearly marked contact penetrated on the Esperson dome. With the exception of two or three sand members, this formation is all shale and sandy shales. To the driller these are "ring-tail" shales. The greatest thinning of any formation on the Esperson dome structure itself occurs in the Vicksburg. Its thickness varies from only approximately 200 feet in the Cranfill-Reynolds Kirby No. 1 to 700 feet in some of the wells drilled on the edge of this uplift. The sand member 200 feet below the top of this formation yields a good showing of oil, and should be proved as a producing zone when tested on the top of the structure.

The Jackson formation is divided into three zones, namely, Whitsett, McElroy, and Caddell. The "T" *Hockleyensis* marks the top of the McElroy. The *Dibollensis* fossil zone represents the top of the Caddell. This group consists entirely of shales, blue and dark colors predominating. The extreme thinning which occurred in the Vicksburg is also found in the Whitsett member. Below the top of the McElroy the beds are more or less constant in thickness. Even in these lower members there is much thinning but it is not so noticeable

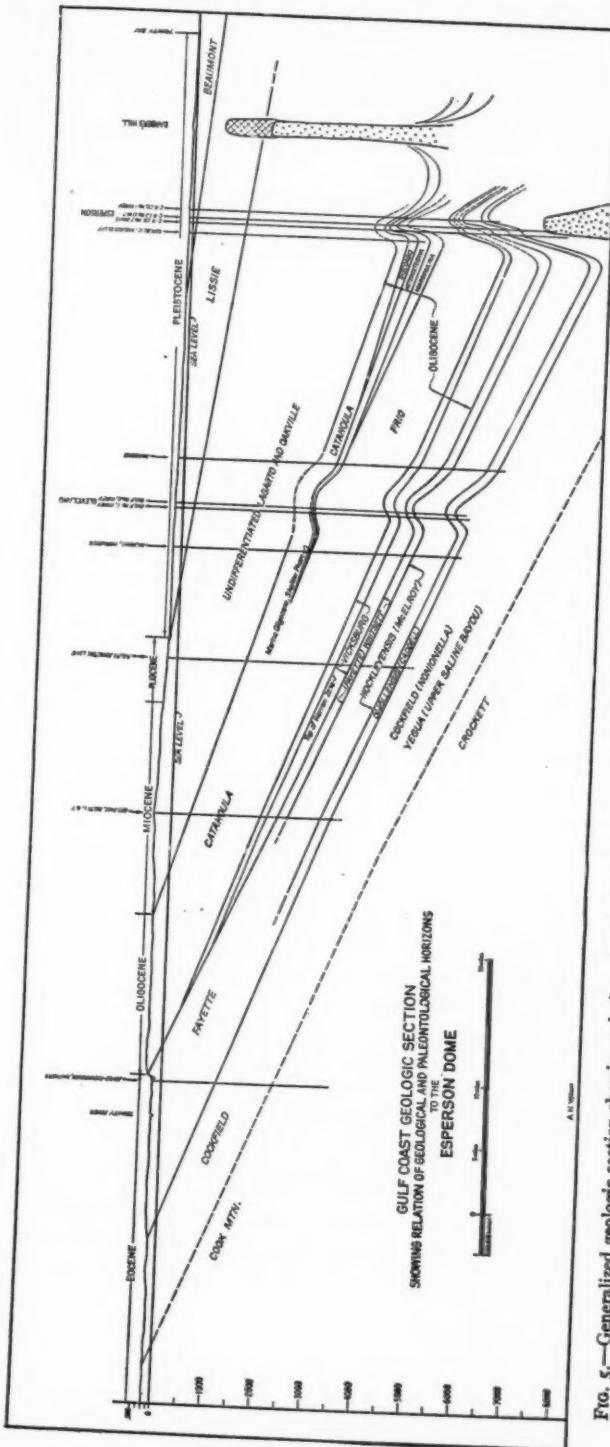


FIG. 5.—Generalized geologic section showing relation of various beds and paleontologic markers to outcrops. Also shows relation of Epsom dome to Rayburn anticline.

as that in the Whitsett and Vicksburg. The Jackson formation varies in thickness from 500 to 1,000 feet. The Whitsett member averages 150 feet in thickness; the McElroy member is approximately 300 feet thick; and the Caddell is approximately 180 feet thick.

Brownish and maroon shales compose the upper part of the Claiborne. These shales are much harder and more compact than the Jackson shales. The Claiborne formation consists of two members, the Cockfield and the Yegua. The Cockfield is shale and ranges in thickness from nearly 0-50 feet. The Yegua consists of sand, shales, and sandy shales, and its thickness, as found in the Yount-Lee Esperson No. 3, is at least 2,000 feet. Moore's Bluff No. 10 penetrated 850 feet below the top of the Claiborne. In this well the bottom 200 feet was salt, this salt occurring from 7,238-7,428 feet. Esperson No. 5 was drilled approximately 300 feet below the top of the Claiborne. Davis No. 7 penetrated the Yegua somewhat more than 800 feet. The Cranfill-Reynolds Company's Kirby No. 1 was drilled about 200 feet into the Yegua beds. In this well, salt was found at 6,030-6,060 feet, this depth being about 100 feet below the top of the Yegua. Below this 30-foot bed of salt, Yegua sands and shale were found to a total depth of the hole at 6,130 feet. There is no production at this time from the Claiborne. However, the drilling of the foregoing wells has proved the existence of at least three productive gas horizons. These occur at approximately 300, 600, and 1,000 feet, respectively, below the top of the Cockfield. Moore's Bluff No. 10 and Kirby No. 1 each showed some oil at 7,070 and 6,150 feet, respectively.

GEOPHYSICAL STRUCTURE

From surface indications alone, there is no evidence of an uplift in the Esperson field. This dome was discovered as a direct result of a torsion-balance survey. Figure 5 is a copy of the original torsion-balance map made by Christian Iden. As a comparison with this map, the writers also present in Figure 6 a seismograph map prepared in 1930, 2 years after the discovery well, by Piepmeyer and Company. This work was a combination of refraction and reflection shooting. No attempt was made by this company to contour the beds but the outlines of the domes in the area were determined as shown on the map.

SUBSURFACE STRUCTURE

The Esperson dome is more or less typical of structures of this type on the Gulf Coast. There is little uplift on the surface beds. The uplift increases in intensity with depth. The uplift in the Miocene

ESPERSON DOME, LIBERTY COUNTY, TEXAS 1641

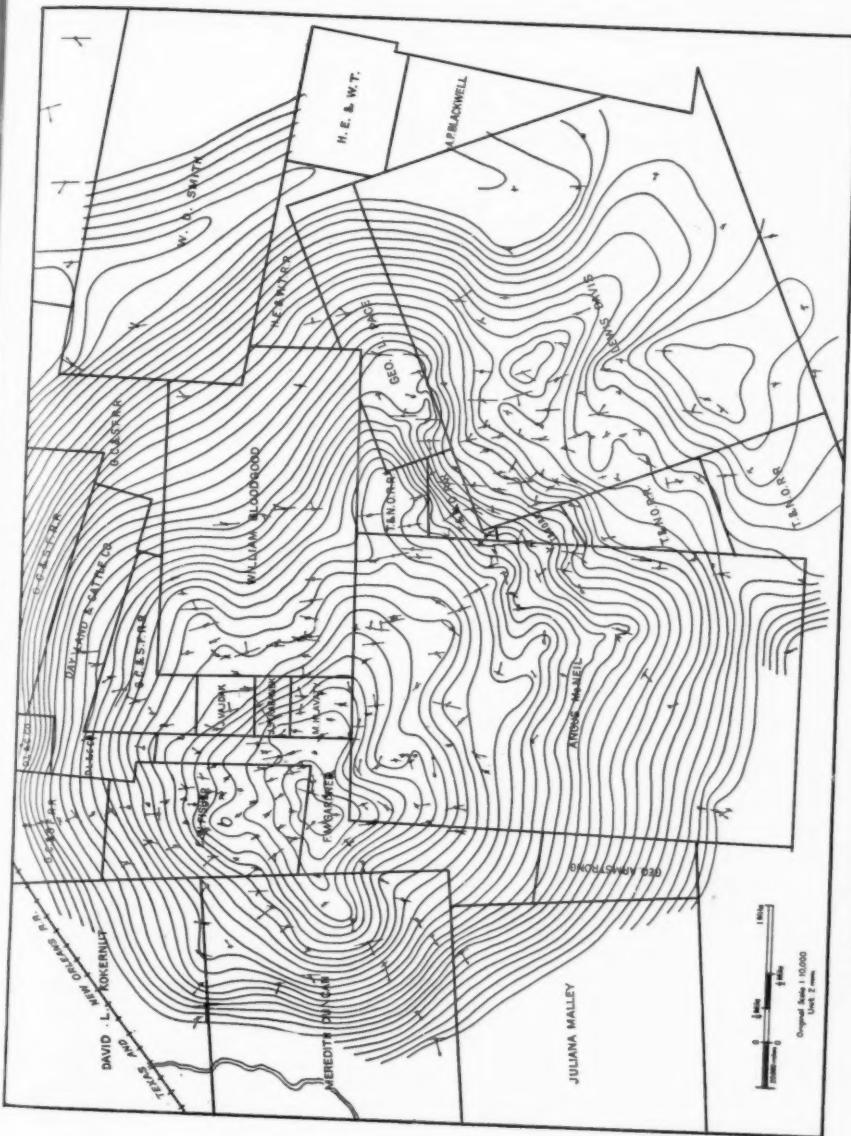


FIG. 6.—Copy of original torsion-balance map of Esperson dome made by Christian Iden.

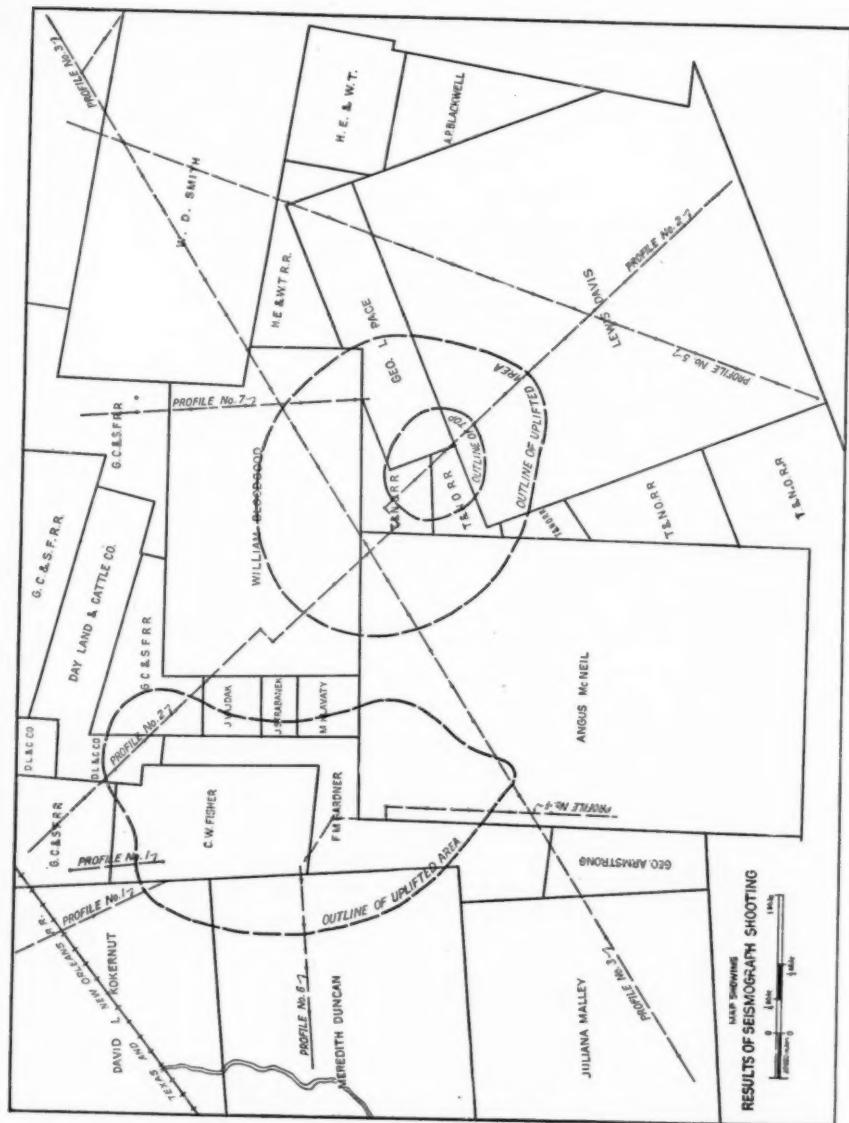


FIG. 7.—Seismograph map of Esperon dome prepared in 1930 by Piepmeyer and Company.

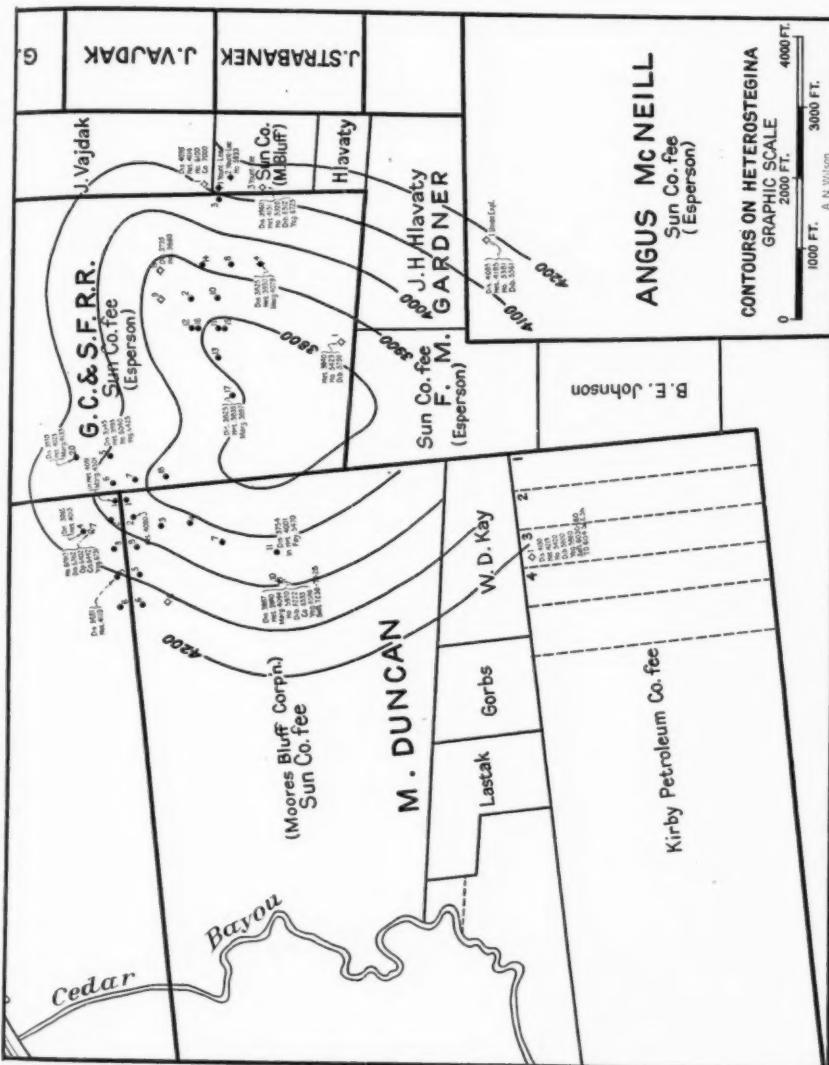


FIG. 8.—Structure map of Esperson dome contoured on top of *Heterostegina* member of Oligocene.

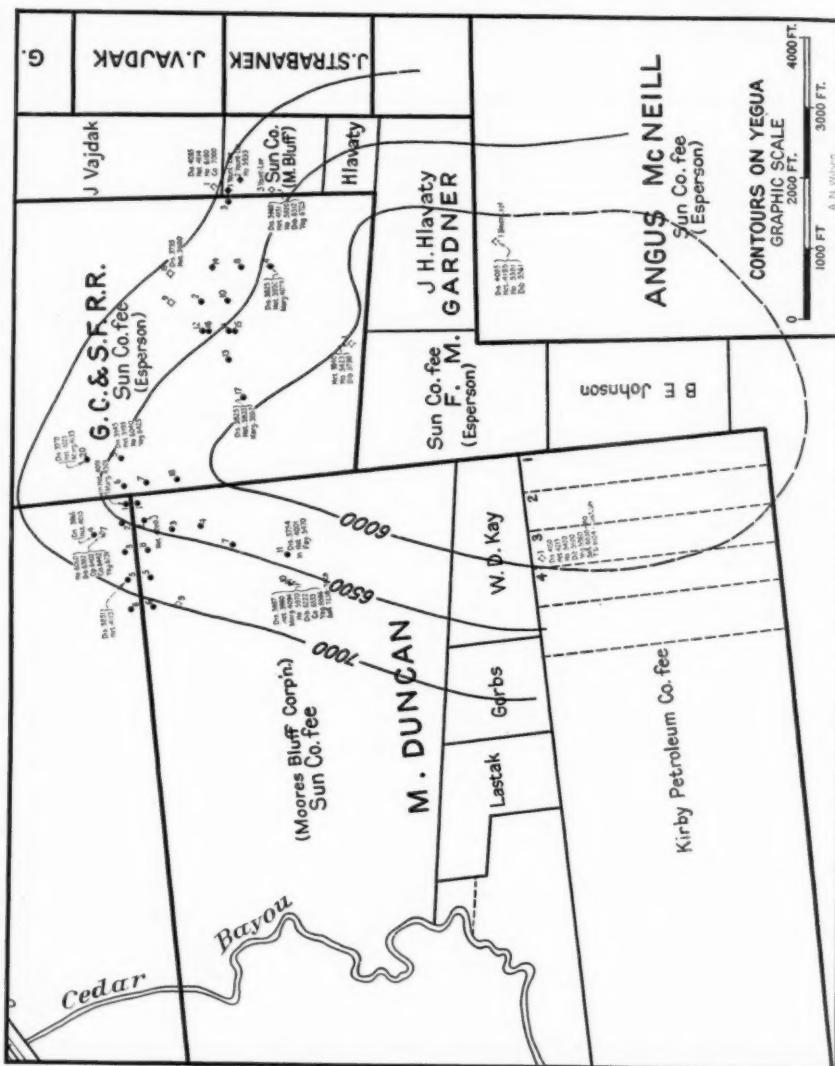


FIG. 9.—Structure map of Esperson dome contoured on top of Yegua.

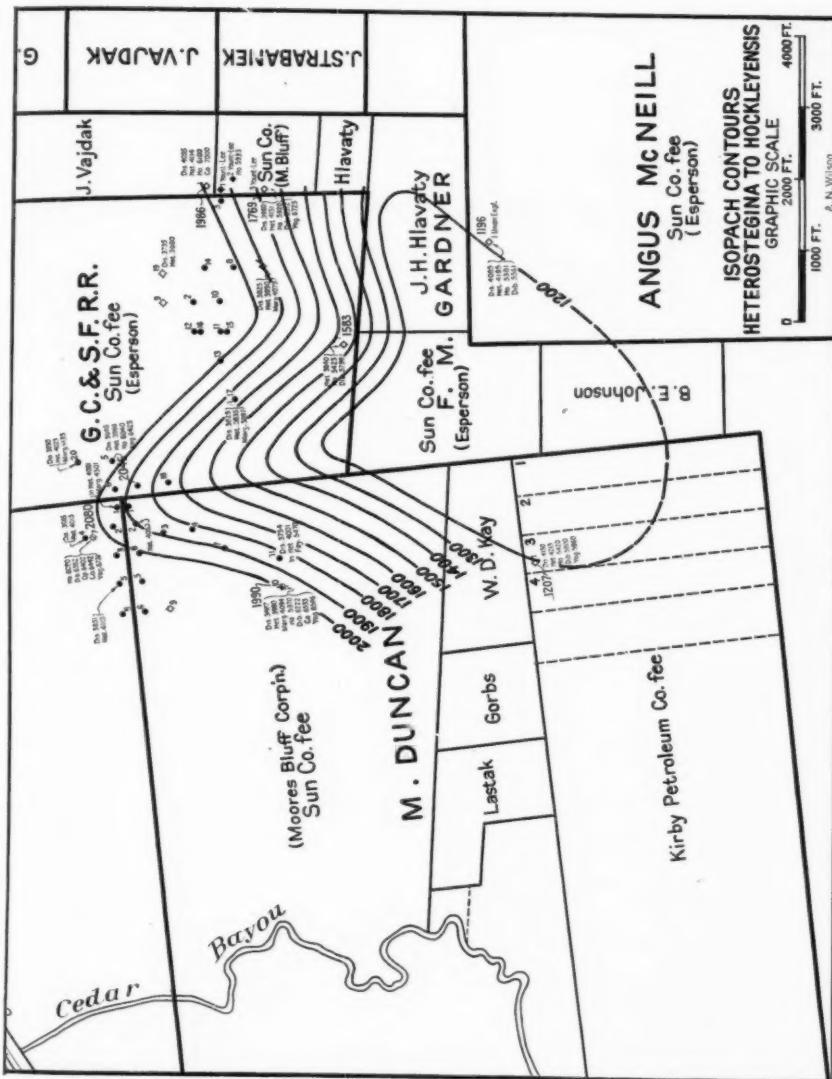


FIG. 10.—Isopach map of Epserson dome showing thinning between *Heterostegina* limestone member of Oligocene and McElroy formation.

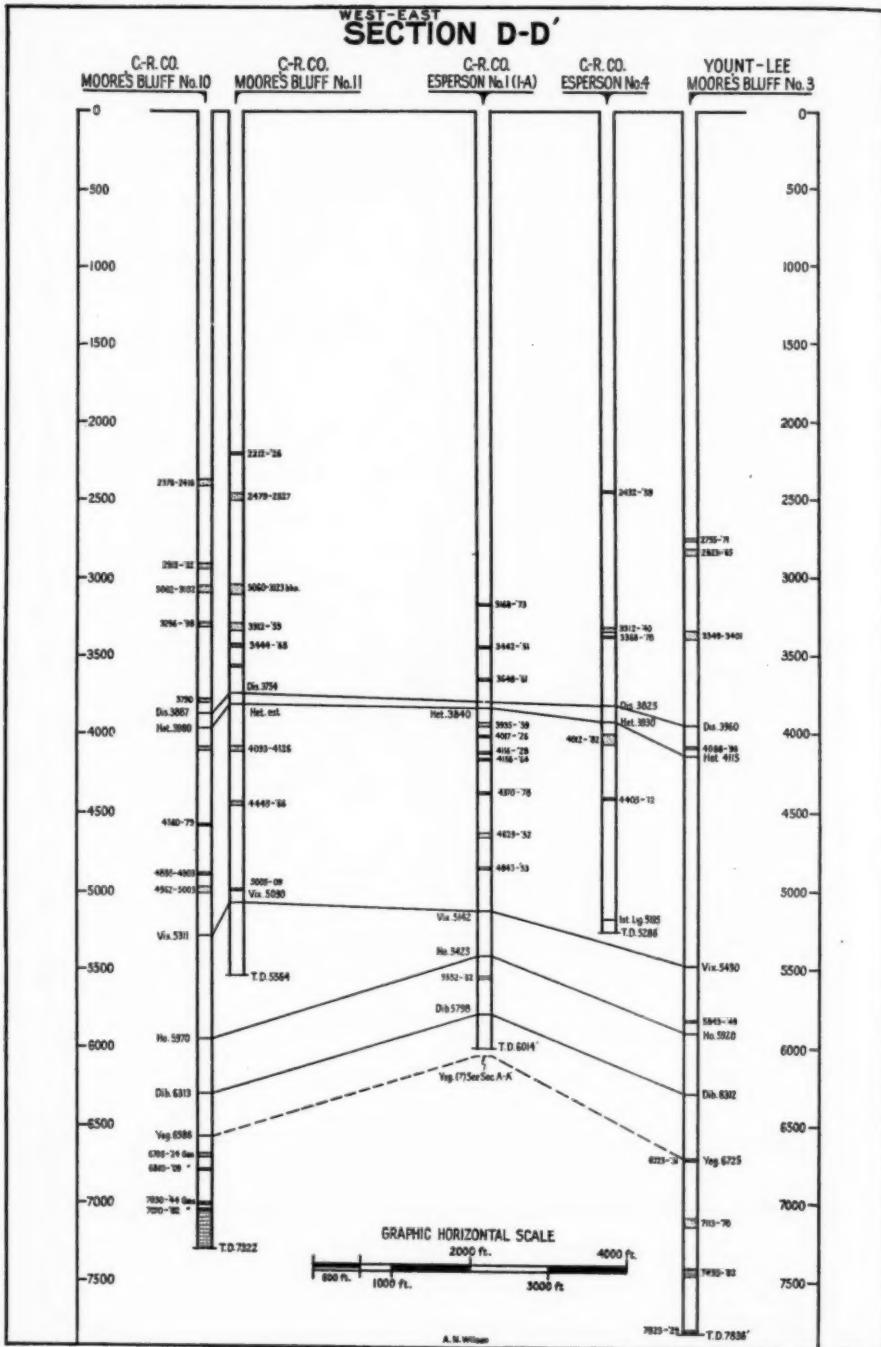


FIG. 11.—West-east section (DD', Fig. 3) of Esperon dome producing area.

**NORTHWEST-SOUTHEAST
SECTION A-A'**

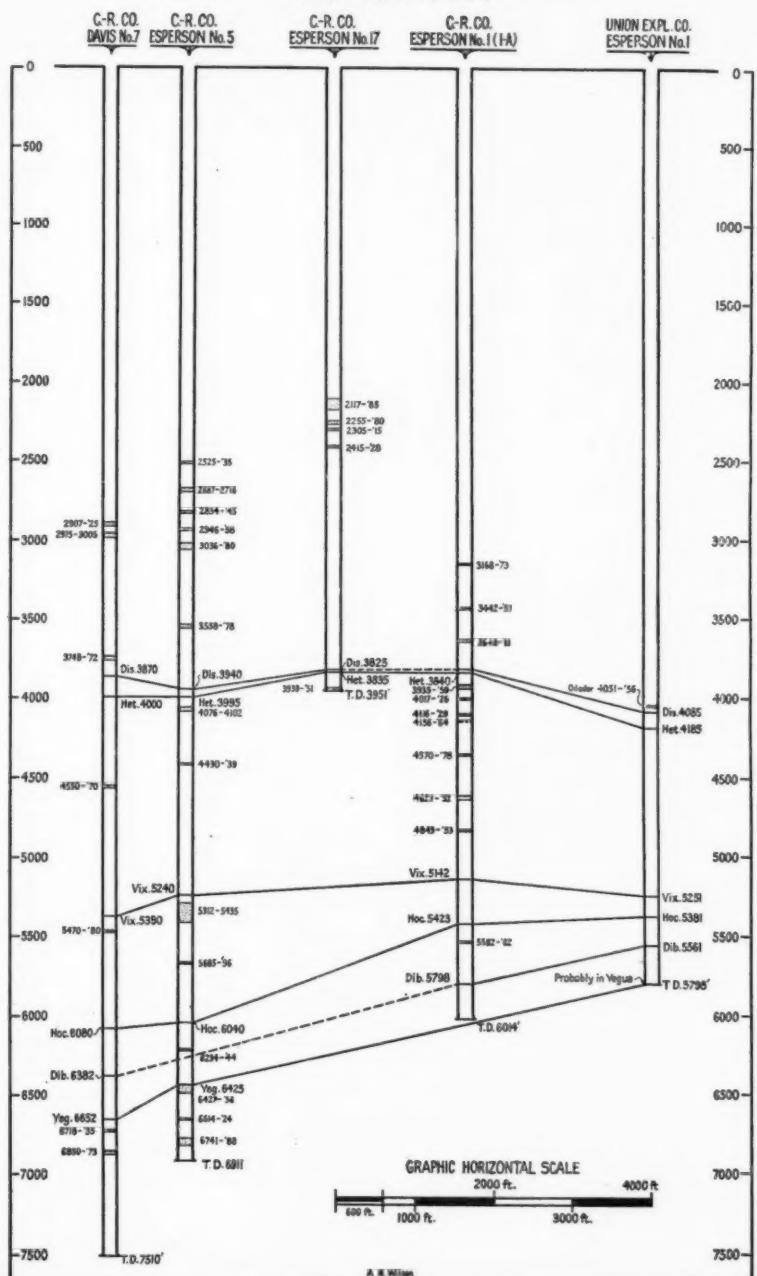


FIG. 12.—Northwest-southeast section (AA' , Fig. 3) of Esperson dome producing area.

SW-NORTHEAST
SECTION B-B'

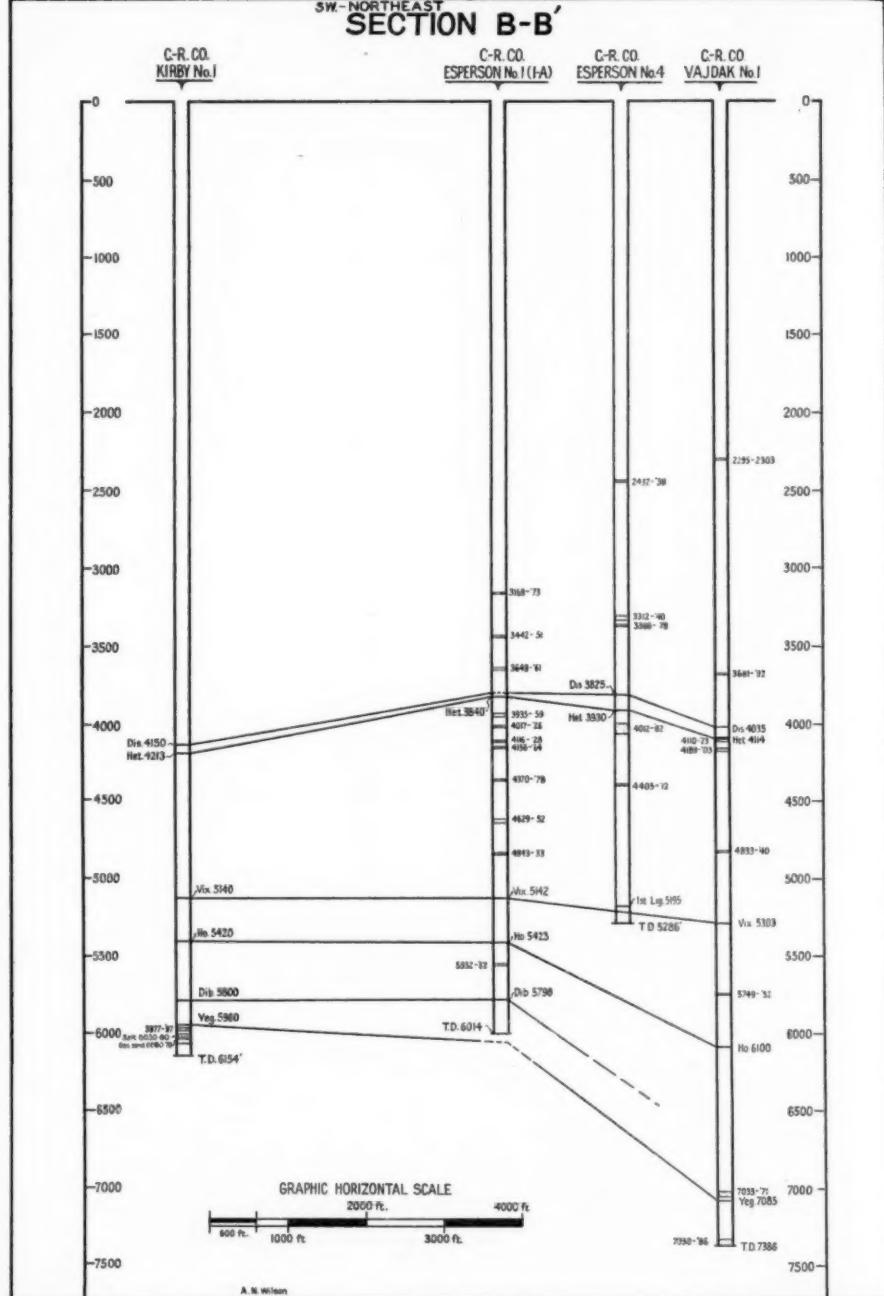


FIG. 13.—Southwest-northeast section (BB', Fig. 3) of Esperson dome producing area.

SOUTH-NORTH
SECTION C-C

C-R CO.
KIRBY No.1

C-R CO.
MOORE'S BLUFF No.10

C-R CO.
DAVIS No.7

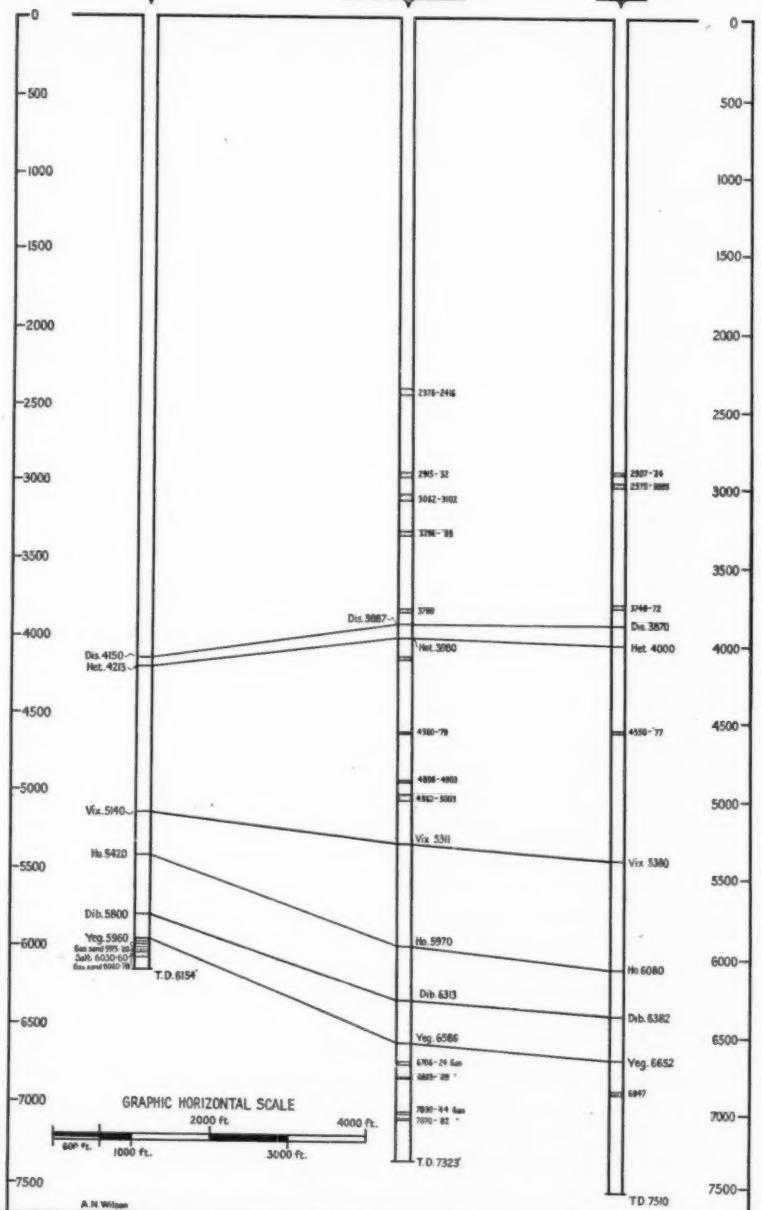


FIG. 14.—South-north section (C-C, Fig. 3) of Esperson dome producing area.

beds is approximately 300-500 feet, that in the Oligocene beds is 500-800 feet, and the maximum uplift in the Yegua formation is 2,500 feet. The top of the structure, as reflected in the Miocene and Oligocene beds, covers about 700 acres; that reflected in the Yegua beds covers probably 1,500 acres.

The Esperson dome structure is peculiar in that the top of the dome as reflected in the beds above the salt, changes in horizontal position with depth. The top of the Miocene structure is between Moore's Bluff No. 7 and Esperson No. 17. The top of the Oligocene structure is approximately 2,000 feet south of this. The top of the Yegua uplift, as interpreted from data available at this time, is between the Cranfill-Reynolds Company's Kirby No. 1 and the Union Exploration Company's Esperson No. 1. As now interpreted, the top of the Yegua structure is approximately 0.75 mile south of the top as reflected in the Miocene sands. The high point on the Yegua structure is approximately 300 feet down-dip from the high point on the Oligocene and Miocene contours. It is interesting to note that the top of the Yegua structure coincides with the top of the dome as determined by the torsion balance. This condition of horizontal shifting of the top of these beds with depth is illustrated in Figure 5. Apparently, the salt mass is not standing vertically. It is inclined north of a vertical position. The beds apparently are folded directly above a line projected upward at right angles to the base of the salt mass.

STRUCTURE AND OIL AND GAS ACCUMULATION

The area proved productive in the Miocene and Oligocene sands is approximately 400 acres. Three hundred additional acres are semi-proved in these sands. The oil and gas sands are lenticular, irregular in size and shape, and overlap one another on top and on the flanks of the structure. In general, these sand lenses "shale-out" toward the top of the structure and thicken down the flanks. Each productive lens is a separate oil pool. It has its own critical water level in respect to edge water. In most places bottom water occurs in the basal parts of the sandy member and persists to the highest position occupied by the oil lens. Therefore, water occurs in most of the oil wells during the early part of their life.

The top of the structure as reflected in the Yegua beds is much greater in area than that found at the depths of the Miocene and Oligocene formations. At this depth the top of the uplift is estimated to cover probably 1,500 acres. The salt found in Moore's Bluff No. 10 indicates that a part of this area at the depth of the Yegua beds

ESPERSON DOME, LIBERTY COUNTY, TEXAS 1651

is pierced by the top of the salt dome. Should this be proved, the Yegua production will be found on the flanks of the dome, the outer limits being determined by the critical oil-water contact levels in the various producing horizons.

PRODUCING HORIZONS

On the Esperson dome seven sand members have been found productive of oil. Among these, five occur in beds of Miocene age and two are Oligocene in age. In the Yegua formation, three members have shown gas in commercial quantities. No wells, however, have been completed in these horizons.

The discovery well was in the 3,300-foot horizon. This lens occurs on the northeast side of the structure. Its productive area is less than 100 acres. The oil sand averages in thickness about 40 feet. The highest part of the lens occurs in Esperson No. 2 and No. 13 at a depth of approximately 3,160 feet. The oil-water contact occurs at approximately 3,340 feet. Esperson wells Nos. 2, 3, 4, 8, 10, 13, 14, 15, and 16 were completed as producers from this lens. Yount-Lee's Esperson wells No. 1 and No. 2 were also completed in this sand. Moore's Bluff No. 10 on the west side of the dome found a productive sand in this horizon. This, apparently, is a separate lens, the areal extent of which is undetermined.

The 2,300-foot sand lens apparently covers more area than that of any of the productive lenses outlined by the drill to date (March 1, 1934). This lens is on the northwest side of the dome and covers approximately 200 acres. Davis wells Nos. 1, 2, 3, 4, 5, and 6, Moore's Bluff Nos. 1, 2, 3, 4, 5, 6, 7, and 8, and Esperson wells Nos. 6 and 7 were originally completed in this sand. The average thickness of the oil horizon in this sand is 30 feet. The highest producing well in this lens is found in Moore's Bluff No. 7 at approximately 2,200 feet. The oil-water contact occurs at about 2,350 feet. Another lens is found on the northeast side of the dome. Esperson No. 2 was originally completed in this sand. Esperson Nos. 11, 12, and 17 were also productive in this zone. The areal extent of the lens has not been determined by the drill.

The 2,400-foot lens occurs also on the northeast side of the uplift. This sand was found in Esperson No. 11 and No. 12. The areal extent of the lens is undetermined.

The 3,100- and 3,500-foot sand lenses are on the north and northwest sides of the dome. Both sands have been found in Moore's Bluff No. 10 and No. 11 and in Esperson Nos. 5, 18, and 20. Davis No. 1 produced for a time from the 3,500-foot sand. At present, Moore's

Bluff No. 1 is the only well producing from the 3,500-foot sand. Esperson wells Nos. 5, 6, and 20 are producing from the 3,100-foot sand. The areal extent and the critical water level in these sands have not been determined.

The 4,100-foot sand horizon is approximately 100 feet below the *Heterostegina* limestone member in the Oligocene formation. This horizon approaches more nearly a blanket sand condition than any of the other producing horizons. It produces in Davis Nos. 1, 2, and 4, Moore's Bluff No. 2, and Esperson No. 18. The zone was also found in the Union Exploration Company's Esperson No. 2, the Cranfill-Reynolds Company's Esperson Nos. 5, 9, and 17, and in the latter company's Moore's Bluff Nos. 10 and 11. The average thickness of the oil sand is about 20 feet. The lower members of this zone contain water over the top of the structure.

Moore's Bluff No. 11 is producing from the sand member at approximately 4,500 feet. This horizon was also found in Esperson No. 5 and in Union Exploration Company's Esperson No. 2. This sandy zone apparently covers the top of the dome.

Gas has been found in three members of the Yegua formation. These sand members occur at approximately 300, 600, and 1,000 feet, respectively, below the top of the Yegua. The upper member averages about 50 feet in thickness. The middle member is 10-60 feet thick. Only one well has been drilled to the lower member. This sand was penetrated by Yount-Lee Esperson No. 3 about 7 feet. As this member was not penetrated, the thickness is undetermined. The Yount-Lee Esperson No. 3 found gas in both the lower and middle members. A little below 7,400 feet this well blew out with an estimated volume of 50 million cubic feet of gas coming from the second sand member in the Yegua. The Cranfill-Reynolds Company's Esperson No. 5 produced gas and distillate for about 1 year from the upper sand horizon at approximately 6,730 feet. The same company's Davis No. 7 also produced gas and distillate for a time from this horizon at a depth of approximately 6,900 feet. Moore's Bluff No. 10 penetrated the upper and middle producing members of the Yegua beds. These members occur at approximately 6,900 and 7,070 feet, respectively. Gas was found in the upper member and both gas and oil in a limited quantity in the second member. The Cranfill-Reynolds Company's Kirby No. 1 found gas in the upper member at a depth of approximately 6,130 feet. At this depth some oil also was found.

HISTORY OF UPLIFT

Growth of the Esperson dome began before the close of Claiborne time. The movement of the salt intrusion began before the close of

ESPERSON DOME, LIBERTY COUNTY, TEXAS 1653

the deposition of the Yegua beds. The thick deposits of these beds as found in Yount-Lee Esperson No. 3 indicates that this dome movement was either in a quiescent period during the deposition of the Yegua or did not begin until near the close of this period. The absence of the Cockfield member of the Yegua over most of the dome and the thinning, as found in the Cranfill-Reynolds Company's Kirby well No. 1, of the interval between the top of the Claiborne and the first sand member in the Yegua, as compared with that found in wells lower on the structure, indicate very clearly that the uplift was progressing before the close of the Claiborne period. This movement continued through the Eocene, Oligocene, Miocene, and probably into the Pliocene period of time. Apparently, the greatest intensity of the movement occurred near the close of the Eocene and during early Oligocene time. The Whitsett member of the Jackson and the Vicksburg member of the Oligocene are practically missing on top of the structure, as indicated by the thin section of this group of sediments found in the Cranfill-Reynolds Company's Kirby No. 1 and the Union Exploration Company's Esperson No. 1. The absence of sands indicates that even during this period, as was the case in early and middle Jackson time, the area was submerged and was probably a submarine knoll. At the beginning of the Frio seas, the Esperson dome became the scene of a series of oscillations which alternately brought its crest above or depressed it below the plane of erosion and deposition. During these oscillations, numerous sand lenses were deposited, overlapping one another and intermingling with shales and clays. By late Pliocene time, the Esperson dome had reached a stage of quiescence. The normal thickness of the Lissie and the undisturbed position of the Beaumont clays indicate that this quiescent period has continued.

GENERAL PRODUCTION DATA

The average initial production of the Esperson dome oil wells is about 300 barrels daily. Because of the low pressure in this field, some of the wells initially do not flow. The average life of the flowing wells is about 60 days. Twelve months is the maximum flowing life of any well in the field. There are now (March 1, 1934) twenty-five oil wells, six wells having been either shut down temporarily or abandoned. The active wells are being pumped.

The total production from the field to date (March 1, 1934) is approximately 2,700,000 barrels of oil, or almost 7,000 barrels per proved acre. The average production per well to date (March 1, 1934) is approximately 80,000 barrels of oil. The present daily production

is 1,300 barrels of oil. The average production of water is approximately 4 barrels for each barrel of oil.

The oil being produced in this field is Grade "A" Gulf Coast crude. The Miocene sands produce 22° gravity oil and the two horizons in the Oligocene formation produce 25° gravity oil. Analyses of these oils from Cranfill-Reynolds wells are here given.

ANALYSIS OF OIL FROM 3,300-FOOT MIOCENE SAND IN ESPERSON NO. 4

Gravity	21.9° A.P.I.
Paraffine	0.21%
Sulphur	0.24%
Flash	260
Fire	300
Viscosity	702 at 82°F. 393 at 100°F. 182 at 130°F.

ANALYSIS OF OIL FROM 4,100-FOOT OLIGOCENE SAND IN DAVIS NO. 1

Gravity	24.8° A.P.I.
Paraffine	0.21%
Sulphur	0.20%
Gasoline	7.50%
Light oil gas	19.80%
Bottoms	72.48%
Loss	0.10%

ANALYSIS OF DISTILLATE FROM 6,700-FOOT YEGUA SAND IN ESPERSON NO. 5

Gravity	55.1°
Navy gasoline A	165.00
Navy gasoline B	138.00
Navy gasoline C	104.28
Gasoline (Int.—410)	195.40
Paraffine	.005%
Sulphur	.006%
Bottoms	4.20%
Loss	0.389%

PHOSPHORIA AND DINWOODY TONGUES IN LOWER CHUGWATER OF CENTRAL AND SOUTHEASTERN WYOMING¹

HORACE D. THOMAS²
Laramie, Wyoming

ABSTRACT

Marine limestone and sandstone tongues extend southeastward from the Phosphoria and the Dinwoody formations of the Wind River Mountains and the Owl Creek Mountains, interfingering with the red shales in the base of the Chugwater formation in central and southeastern Wyoming. The intercalated marine beds and red shales constitute the red-bed "Embar" of central Wyoming. The nature of the lateral change from the Phosphoria and the Dinwoody facies to the red-bed Chugwater facies is described.

INTRODUCTION

Do the typical marine sediments of the Phosphoria and the Dinwoody formations of the Wind River Mountains grade eastward into red beds? The opposing views of various investigators led the writer to make a detailed stratigraphic study of the relations of the Phosphoria and the Dinwoody formations to the red-bed "Embar" of central Wyoming and to the red Satanka shale, the Forelle limestone, and the Chugwater red beds of the Laramie Basin.

In 1906, Darton³ applied the name, Embar formation, to a succession of beds which occur above the Tensleep sandstone (Pennsylvanian) and below the red Chugwater shale (Triassic?) on the north flank of the Owl Creek Mountains in north-central Wyoming (Fig. 1). Blackwelder⁴ subsequently gave the name, Dinwoody formation⁵ (Fig. 2), to the drab sandstones and shales composing the upper part of Darton's Embar, and correlated the lower portion of the Embar with the Park City formation of Utah. Previously, Richards and

¹ Manuscript received, September 9, 1934.

² University of Wyoming.

³ N. H. Darton, "Geology of the Bighorn Mountains," *U. S. Geol. Survey Prof. Paper 51* (1906), p. 35. "Geology of the Owl Creek Mountains," *59th Cong., First Session, Sen. Doc. 219* (1906), pp. 17-18.

⁴ Eliot Blackwelder, "New Geologic Formations in Western Wyoming," *Jour. Washington Acad. Science*, Vol. 8 (1918), pp. 417-26.

⁵ Type locality: Dinwoody Canyon, Wind River Mountains.

Mansfield⁶ had applied the name, Phosphoria formation, to the upper two members of the Park City. Since the time of Blackwelder's work, it has been found that the portion of the Embar which he called



FIG. 1.—Index map of central and southeastern Wyoming.

Park City corresponds to only the Phosphoria portion of the Park City of the type locality. Consequently, the name, Phosphoria, is now

UTAH & SOUTHEASTERN IDAHO		WIND RIVER & OWL CREEK MOUNTAINS, WYOMING		
BOUTWELL 1907	RICHARDS & MANSFIELD 1912	DARTON 1906	BLACKWELDER 1918	CONDIT 1924
		EMBAR	DINWOODY	DINWOODY
PHOSPHORIA			PARK CITY	PHOSPHORIA
PARK CITY				

FIG. 2.—Evolution of nomenclature of Phosphoria and Dinwoody formations.

used for the lower portion of Darton's Embar, and the upper portion is known as the Dinwoody formation.

⁶ R. W. Richards and G. R. Mansfield, "The Bannock Overthrust," *Jour. Geol.*, Vol. 20 (1912), p. 684.

The name, Chugwater formation, had been given by Darton⁷ to . . . the series of red beds extending along the foot of the Bighorn range southward through Wyoming and Colorado.

In its original definition the name included all the beds above the Tensleep sandstone and below the Sundance formation (Jurassic).

In central Wyoming a succession of alternating red shales and limestones occupies essentially the same stratigraphic position as the Embar of the type locality and was originally included by Darton⁸ in the base of his Chugwater formation. These beds rest upon the Tensleep sandstone and are overlain by the main body of the red shales of the Chugwater. Even though they differ in character from the type Embar, that name was carried southward, and they also became known as "Embar." Lee⁹ believed the succession to be younger than the type Embar and designated it as "The Embar of Oil Geologists." Others have indicated it as "Embar (?) formation." Controversy has arisen as to the relation of the red shales and limestones to the Phosphoria and the Dinwoody formations.

In the Laramie Basin the red Satanka shale and the Forelle limestone were named and removed from the base of Darton's original Chugwater by Darton and Siebenthal.¹⁰ The Satanka overlies the Casper formation (Pennsylvanian) and is separated from the main body of the red shales of the Chugwater by the Forelle limestone. The Satanka and the Forelle have heretofore been recognized as bearing some indefinite relation to the red-bed "Embar" of central Wyoming.

Disregarding those writers who have stated in a casual manner that the Phosphoria and the Dinwoody do, or do not, grade into red-beds, the present status of the problem of the stratigraphic relations of the formations may be summarized as follows.

Condit¹¹ studied the Embar of the type locality and reached the conclusion that the beds now known as Phosphoria and Dinwoody in the Owl Creek Mountains are represented farther east in the Bighorn

⁷ N. H. Darton, "Comparison of the Stratigraphy of the Black Hills, Bighorn Mountains and Rocky Mountain Front Range," *Bull. Geol. Soc. America*, Vol. 15 (1904), p. 397.

⁸ *Op. cit.*, p. 397.

⁹ Willis T. Lee, "Correlation of Geologic Formation between East-Central Colorado, Central Wyoming and Southern Montana," *U. S. Geol. Survey Prof. Paper* 149 (1927).

¹⁰ N. H. Darton and C. E. Siebenthal, "Geology and Mineral Resources of the Laramie Basin, Wyo.," *U. S. Geol. Survey Bull.* 364 (1909).

¹¹ D. D. Condit, "Relations of the Embar and Chugwater Formations in Central Wyoming," *U. S. Geol. Survey Prof. Paper* 98 (1916).

Mountains by a succession of red beds. Later, however, Lee¹² concluded that the Phosphoria and the Dinwoody formations are cut off farther east by an unconformity and that the red beds known in central Wyoming as "Embar," and also the Satanka shale and the Forelle limestone of the Laramie Basin, are younger than the beds originally called Embar.

More recently C. C. Branson has advanced a slightly different view. He reworked the area between the Owl Creek and the Bighorn Mountains which had been discussed by Condit, and also noted that the stratigraphic interval occupied in the Owl Creek Mountains by the Phosphoria and Dinwoody formations is occupied in the Bighorn Mountains by a red-bed series, which, in his opinion,

. . . is continuous with and entirely similar to the overlying Chugwater.

He believes,

that the area now occupied by the Bighorn Mountains was above the sea and was being eroded while the Phosphoria and Dinwoody formations were being deposited to the west.¹³

Three relationships, then, have been suggested up to the present. (1) Condit's belief of gradation between the Phosphoria and the Dinwoody and the red-bed "Embar," (2) Lee's view that a post-Dinwoody unconformity separates the Phosphoria and the Dinwoody from the red beds, and (3) Branson's belief that the base of the Chugwater is homotaxial and that certain areas in Wyoming were being eroded and received no sediments during Phosphoria and Dinwoody time.

Field Work.—Condit and Branson both traced the Phosphoria and the Dinwoody from the Owl Creek Mountains into the Bighorn Mountains with a resultant conflict in their interpretations. Lee traced the red beds from the Laramie Basin northward to the Owl Creek Mountains and then made studies along the Wind River range. The writer, following a different course, traced the Phosphoria and the Dinwoody from the Owl Creek Mountains along the Wind River Mountains to the southern end of that range (Fig. 1), thence eastward to the Green Mountains, the Ferris Mountains, and the Freeze-out Hills, and southward along the west flank of the Laramie Mountains to the southern end of the Laramie Basin. Studies were also made in the Rattlesnake Hills and in the region around Alcova. Field work was carried on at intervals from the summer of 1929 to 1933 and the writer is still actively engaged in the investigation of these strata.

¹² *Op. cit.*

¹³ C. C. Branson, "Paleontology and Stratigraphy of the Phosphoria Formation," *Univ. of Missouri Studies*, Vol. 5, No. 2 (1930), pp. 5-6.

The study of the beds is made difficult by the fact that they can not be traced continuously, being concealed in many areas by Tertiary deposits. In addition, the red beds lie immediately above the resistant Tensleep sandstone which forms hogbacks. Consequently, the red beds, which are relatively nonresistant, are covered, in many places, by debris derived from the Tensleep.

Acknowledgments.—The writer is indebted to the following for aid in completing this paper. S. H. Knight made available the facilities of the Geological Survey of Wyoming and contributed many valuable suggestions; R. H. Beckwith aided in revising and criticizing the type-script; J. B. Reeside, Jr., suggested a system of stratigraphic nomenclature; A. K. Miller studied and identified the cephalopods; C. O. Dunbar checked the identifications of some of the brachiopods; G. R. Mansfield examined specimens of brecciated chert, and H. G. Walter furnished his list of Dinwoody fossils and his conclusions regarding their age.

In addition, the writer wishes to thank the members of the faculty of the department of geology at Columbia University for their kindness in criticizing the interpretations here set forth. The suggestions of G. M. Kay, H. N. Coryell, and Ida H. Ogilvie have proved especially valuable.

SUMMARY OF CONCLUSIONS

It is the purpose of this paper to show that limestone and sandstone tongues extend east and south from the Phosphoria and the Dinwoody formations of the Wind River and the Owl Creek mountains and interfinger with the red shales in the base of Darton's original Chugwater formation of central and southeastern Wyoming. The intercalated limestones, sandstones, and red shales constitute the red-bed "Embar" of central Wyoming. Eastward the red shales become thicker and more prominent and the Phosphoria and Dinwoody tongues, thinner and less conspicuous. Each larger tongue is split into minor tongues by interfingering with tongues of different lithology. It is believed that Phosphoria and Dinwoody tongues may be traced and recognized over a much greater area than that discussed in this paper.

The Phosphoria formation of the Wind River Mountains is the time equivalent of the lower portion of the red-bed "Embar" of central Wyoming. The Phosphoria is represented in the Laramie Basin by the Satanka shale, the Forelle limestone, and a portion of the basal Chugwater. The Dinwoody formation of the type locality is equivalent to the upper portion of the red-bed "Embar" and to a

portion of the lower Chugwater at localities east and south of the Wind River and the Owl Creek mountains.

The beds in the region covered by this paper show an interfingering of the Phosphoria and the Dinwoody with the lower part of the Chugwater formation similar to the interfingering described by Condit for the region between the Owl Creek and the Bighorn mountains. Lee's post-Dinwoody unconformity is believed not to be present in central and southeastern Wyoming, and his view that the red-bed "Embar" is younger than the Phosphoria and the Dinwoody formations is apparently not a tenable one. In this area no evidence was found supporting Branson's theory of local positive areas during Phosphoria and Dinwoody time, as central and southeastern Wyoming was entirely covered by sediments of Phosphoria and Dinwoody age.

STRATIGRAPHIC NOMENCLATURE

The interfingering of the Phosphoria and the Dinwoody with the Chugwater brings about troublesome problems in nomenclature. Limestones and sandstones extending eastward from the Wind River Mountains between red shales are treated as *tongues* of the Phosphoria and the Dinwoody formations. If there should be a locality at which all Phosphoria and Dinwoody tongues have thinned out, although such a section is unknown, it would then be impossible to differentiate the Phosphoria, the Dinwoody, and the Chugwater portions of the red shale series, and the entire sequence would be designated as Chugwater. Hence, all the red shales extending westward from central Wyoming into the Phosphoria and the Dinwoody formations are treated as tongues of the Chugwater formation.

In this paper, beds of Phosphoria age having the typical lithologic character of the Phosphoria formation, comprise the Phosphoria facies; those of Dinwoody age and lithologic character, the Dinwoody facies. The Chugwater facies is represented by red beds. The term *intertongued phase* is applied to sections in which the Phosphoria and the Dinwoody facies are intertongued with the Chugwater red-bed facies.

Following this system of nomenclature the Chugwater becomes a lithologic unit embracing rocks of both Permian and Triassic age, and a unit with a different age for its basal beds in different localities. Nevertheless, as J. B. Reeside, Jr.,¹⁴ points out:

It seems . . . absurd that in the case where we have no fossils and no usable lithologic differences, we should attempt a separation into hypothetical

¹⁴ Personal communication.

units based on tracing an invisible line from another area where the line happens to be real. That homogeneous lithologic units cover different intervals at different localities is a natural condition. It is simply a logical part of our nomenclatorial system that our names for such units have one scope at one place and another at a different place.

The new names of units introduced are available as stratigraphic names, none being preoccupied. The following new stratigraphic units are defined and described within this paper: the Sybille tongue of the Phosphoria, the Ervay tongue of the Phosphoria, the Little Medicine tongue of the Dinwoody, and the Freezeout tongue of the Chugwater.

PHOSPHORIA FORMATION

General character.—Because of the occurrence of phosphate rock in the Phosphoria formation, many studies have been made of its features of economic importance. In recent years attention has been given to some of the numerous stratigraphic, paleontologic, and lithogenetic problems presented, and bibliographies on the literature of the Phosphoria have been compiled.¹⁵

The Phosphoria in the Wind River Mountains rests unconformably upon the Tensleep sandstone of Pennsylvanian age. This relationship is indicated by the fact that the Phosphoria rests upon an irregular surface which truncates the cross-lamination of the Tensleep, and by the presence, in places, of material in the basal bed of the Phosphoria that has undoubtedly been derived from the Tensleep sandstone.

There is great vertical lithologic variation in the formation. In the Wind River Mountains it ranges in thickness from 200–300 feet and consists of alternating beds of shales, limestones of different sorts, and unusual rock types, such as bedded cherts and phosphate rock. Limestones predominate and are characteristically cherty. They vary from pure limestones to cherty limestones and pure bedded cherts. Certain strata contain numerous calcite geodes. The shales are argillaceous, siliceous, cherty or phosphatic, and are generally gray or olive-colored. In most places there are two zones of phosphate rock. In the Owl Creek Mountains the formation retains its typical lithologic character but is considerably thinner.

The region between the southern end of the Wind River Mountains and the Green Mountains (Fig. 1) is a great area of Tertiary sediments. The Paleozoic rocks are covered nearly everywhere, but at Ice Slough Canyon the Phosphoria is partially exposed. The exposed portion is

¹⁵ D. D. Condit, E. H. Finch, and J. T. Pardee, "Phosphate Rock in the Three Forks-Yellowstone Park Region, Montana," *U. S. Geol. Survey Bull.* 695 (1928), pp. 151–66; C. C. Branson, *op. cit.*

lithologically similar to the Phosphoria of the Wind River Mountains, except for the absence of phosphate beds, and the formation apparently has about the same thickness. The mantle on the covered portion suggests that some red shale may be present.

C. C. Branson¹⁶ and Condit¹⁷ have described in detail the lithologic character of the formation in the Wind River and the Owl Creek mountains. Mansfield¹⁸ has discussed the origins of the chert and phosphate beds.

Age.—The determination of the age of the Phosphoria is a paleontologic problem. At present the age remains in doubt. Girty¹⁹ has given a history of the interpretation of the age of the Phosphoria fauna of southeastern Idaho, which is believed by him to be contemporaneous with a Permian fauna from Alaska which had been examined by Holtedahl, who gave an opinion that the Alaskan fauna was "Artinskian (basal Permian)."

The fish fauna of the lower phosphate member of the Phosphoria of the Wind River Mountains was studied by E. B. Branson.²⁰ He says,

The abundance of cochliodont sharks, which have never been reported from strata younger than the Pennsylvanian, indicates an age older than the Permian.

C. C. Branson studied the fauna of the entire Phosphoria of the Wind River Mountains,²¹ described new species, and arranged the biota into faunal zones. In regard to age he says:

It seems . . . that the formation through the Lower Phosphate member is late Pennsylvanian in age, and that there is a gradation into beds of Permo-Carboniferous age somewhere between the Lower Phosphate and the Pustula member. There is no indication of a stratigraphic break in the lithology. The Pustula and Hustedia faunas are Permo-Carboniferous with Pennsylvanian holdovers, and the Aulosteges fauna is distinctly Permian. From the complete absence of ammonites, however, it must be concluded that the faunule belongs to the lowermost part of the Permian. Here, as in Kansas and Nebraska, is a gradation without a break from Pennsylvanian to Permian.

¹⁶ *Op. cit.*

¹⁷ D. D. Condit, "Phosphate Deposits in the Wind River Mountains, near Lander, Wyoming," *U. S. Geol. Survey Bull.* 764 (1924).

¹⁸ G. R. Mansfield, "Geography, Geology and Mineral Resources of Part of Southwestern Idaho," *U. S. Geol. Survey Prof. Paper* 152 (1927), pp. 361-71; "Some Problems of the Rocky Mountain Phosphate Field," *Econ. Geol.*, Vol. 26, No. 4 (1931), pp. 353-74.

¹⁹ G. H. Girty, in G. R. Mansfield, "Geography, Geology and Mineral Resources of Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper* 152 (1927), pp. 78-81.

²⁰ E. B. Branson, "The Lower Embarras of Wyoming and its Fauna," *Jour. Geol.*, Vol. XXIV, No. 7 (1916), pp. 639-65.

²¹ *Op. cit.*

King, in his work on the Permian brachiopods,²² later pointed out analogies between the fauna of the Phosphoria and that of the Middle Permian Word formation of Texas, and says,

. . . Branson's conclusion that the formation [Phosphoria] lies on the boundary between the Pennsylvanian and Permian must be considered unlikely.

Recently C. C. Branson²³ has described a fish fauna from the middle Phosphoria which in itself throws no new light on the age of the formation. The fauna consists of 11 species, 6 of which occur in the lower Phosphoria, and the remaining 5 are new species. Because of the absence of coeliodont sharks and because of the occurrence of *Punctospirifer pulchra*²⁴ and *Aulosteges hispidus*, he considers the fauna to be Permian.

A. K. Miller has recently found new species of ammonoids about 60 feet below the Rex chert member of the Phosphoria in western Wyoming. *Stacheoceras*, *Vidrioceras*, *Gastrioceras* and *Goniatites* are represented by species which are closely related to known Middle Permian forms. These new species, he says, are almost certainly Middle Permian in age.²⁵

In the light of present knowledge, then, it is necessary to consider the problem an open one. If the lower portion of the formation is Pennsylvanian and the upper portion Middle Permian, there must be an unconformity of considerable magnitude within the formation. Bartram²⁶ has advanced evidence which he believes indicates the presence of such an unconformity. The writer believes that the evidence is inconclusive,²⁷ but admits the possibility of such a hiatus. If the entire formation proves to be Middle Permian, then early Permian time may be represented by the unconformity between the Phosphoria and the Pennsylvanian Tensleep and Casper formations.

²² R. E. King, "Geology of the Glass Mountains, Texas," Pt. 2, *Univ. Texas Bull.* 3042 (1930), pp. 30-33.

²³ C. C. Branson, "Fish Fauna of the Middle Phosphoria Formation," *Jour. Geol.*, Vol. XLI, No. 2 (1933), pp. 174-83; "Permian Sharks of Wyoming and of East Greenland," *Science*, N.S., Vol. 79, No. 2054 (1934), p. 431.

²⁴ *Spirifera pulchra* Meek, 1860, = *Spiriferina pulchra* (Meek), 1860, = *Punctospirifer pulchra* (Meek), 1860.

²⁵ Personal communication.

Since this paper was written these new species have been described. (A. K. Miller and L. M. Cline, "The Cephalopods of the Phosphoria Formation of Northwestern United States," *Jour. Paleontology*, Vol. 8, No. 3 (1934), pp. 281-302.)

²⁶ J. C. Bartram, "Character of Producing Sandstones and Limestones of Wyoming and Montana," *Bull. Amer. Assoc. Petro. Geol.*, Vol. 16, No. 9 (1932), pp. 870-73.

²⁷ Horace D. Thomas, *Bull. Amer. Assoc. Petro. Geol.*, Vol. 17, No. 3 (1933), pp. 268-69.

TONGUES OF PHOSPHORIA FORMATION

Sybille tongue of Phosphoria (new name).—The red Satanka shale around the Sybille anticline near Sybille, Springs (Fig. 1), in the Laramie Basin, contains a fossiliferous sandstone 21 feet thick, lying 184 feet above the base of the Satanka. To this sandstone the name *Sybille*²⁸ tongue of the *Phosphoria formation*, is here applied (Fig. 3). The upper portion is a massive, medium-grained, mottled, pink and buff sandstone containing a great quantity of cylindrical, gray chert nodules oriented in all directions and averaging about $\frac{1}{2}$ inch in

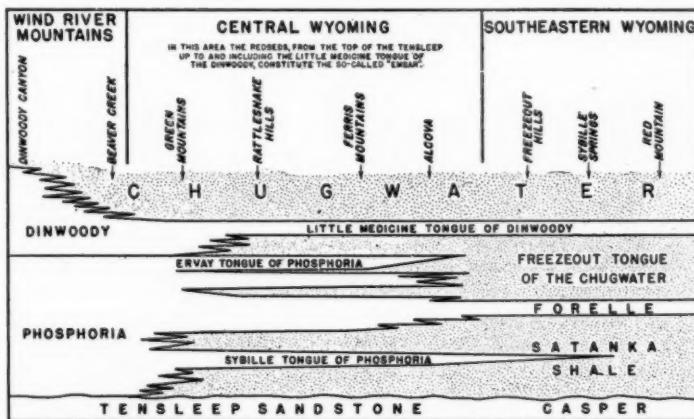


FIG. 3.—Diagram illustrating general relations of stratigraphic units discussed in text. Geographic locations of sections are shown on index map (Fig. 1).

diameter. It grades downward and becomes a thin-bedded limy sandstone containing maroon chert laminae and small, angular, gray chert masses. When freshly broken, the rock of the lower portion shows a distinctive orange-buff color with pink mottlings, but it weathers tan. Calcite geodes up to $1\frac{1}{2}$ inches in diameter are abundant. Fossils are present but poorly preserved, and consist of gastropods and scaphopods, the latter represented by abundant elongate, tapering cones as much as 3 inches in length and $3/16$ inch in diameter. Because of the poor preservation the surface markings are unknown, but, as the specimens are smooth, the writer provisionally refers them to the genus *Plagioglypta*.

The tongue thins southward from Sybille Springs and seems absent

²⁸ Spelling accepted by the U. S. Geographical Board, 1931. Pronounced Sib-beel'.

in the southern part of the Laramie Basin. Toward the north and west it becomes more limy, and the lithology varies considerably. *Plagioglypta?* occurs at many places. The geodes, however, are extremely persistent and have been noted in every locality. The writer has seen similar geodes (Fig. 4) in the lower part of the Phosphoria of the Wind River Mountains, along the Sweetwater River south of Beaver Creek and along Bull Lake Creek, and in the Owl Creek Mountains along the west fork of Sheep Creek, near Holland's ranch.

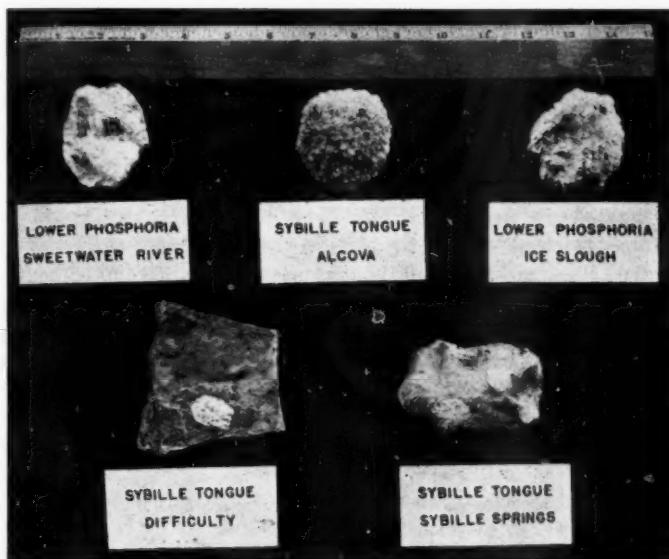


FIG. 4.—Geodes from Phosphoria formation in and near Wind River Mountains and from Sybille tongue of Phosphoria.

Condit²⁹ and C. C. Benson³⁰ also noted them in the Phosphoria. Although similar geodes occur in the upper part of the Phosphoria in certain localities, the writer believes that those in the lower part are probably characteristic of a certain horizon, and that the Sybille tongue corresponds to the geode-bearing limestone near the base of the Phosphoria formation in the Wind River and the Owl Creek ranges.

²⁹ D. D. Condit, "Phosphate Deposits in the Wind River Mountains, Near Lander, Wyoming," *U. S. Geol. Survey Bull.* 764 (1924), p. 12.

³⁰ *Op. cit.*, p. 12.

Forelle limestone.—In the Laramie Basin the Forelle limestone has been taken from the base of the Chugwater and recognized as a distinct formation. It seems to be an extended tongue of the Phosphoria, and consequently may be considered as the "Forelle limestone tongue of the Phosphoria" (Fig. 3). The Forelle loses its identity north and west of the Freezeout Hills and becomes a part of a thicker succession of limestones. Additional detailed stratigraphic work must be undertaken before it can be determined which beds represent the Forelle in that area.

Ervay tongue of Phosphoria (new name).—The uppermost limestones of the Phosphoria extend eastward and southward from the Wind River and the Owl Creek mountains as a fairly widespread tongue. It is here proposed to designate this bed as the *Ervay tongue of the Phosphoria formation*. It crops out a few hundred feet west of Ervay, a postoffice in Natrona County, near the northern end of the Rattlesnake Hills,³¹ and also at such scattered localities as the Ferris Mountains, the Green Mountains, and Alcova (Fig. 1). The tongue is not as well exposed near Ervay as on the head of Casper Creek near Garfield Peak, about 15 miles south of Ervay, where it forms the dip-slope of a prominent hogback. The type section is on Casper Creek. The details of the lithology of the tongue are given in Table I and the fossils present are listed following the table. The thickness of the tongue is fairly constant, but the lithology is quite different in various localities. The tongue includes the uppermost beds of Phosphoria age and is overlain by rocks of Dinwoody age. Consequently, at localities at which the Ervay tongue is present the top of the Phosphoria may be ascertained, and the red shales below this tongue and above the Tensleep sandstone (Fig. 3) are tongues of the Chugwater included in the Phosphoria formation. The beds between the Tensleep sandstone and the top of the Ervay tongue may be referred to as *Phosphoria, with included tongues of Chugwater*.

DINWODY FORMATION

General character.—The Dinwoody formation in the Wind River range consists of alternating shales and sandstones resting with apparent conformity on the uppermost limestone of the Phosphoria. There is a sharp lithologic change at the boundary between the two formations. The shales of the Dinwoody are usually gray in color and alternate with dense, fine-grained calcareous sandstones, which weather

³¹ The Rattlesnake Hills referred to in this paper are those in Natrona County, central Wyoming, and should not be confused with other localities in Wyoming known by the same name.

tan, brown, or black. Many of the beds contain abundant flakes of muscovite. Blackwelder³² has pointed out that the formation becomes thicker and more calcareous westward from the Wind River Mountains. The thickness ranges from 254 feet at the type locality in Dinwoody Canyon to 37 feet at Beaver Creek near the southeastern end of the Wind River range. At Beaver Creek the formation consists of a basal, gray clay shale 10 feet thick, which contains small limonitic concretions and numerous red streaks. This bed rests upon the top cherty limestone of the Phosphoria and grades upward into 7 feet of gray limy and shaly, fine-grained sandstone. The uppermost 20 feet of the formation is harder and forms a ledge of thinly bedded, fine-grained, finely laminated, highly calcareous gray sandstone containing small flakes of muscovite. The top 3 or 4 feet is most sandy, is highly ripple marked, and some of the bedding planes are covered with fucoidal markings. This bed is overlain by red Chugwater shale.

The contact of the Dinwoody and the overlying Chugwater is, in some places, transitional. At the type locality of the Dinwoody, the upper gray shales grade upward into the red shales of the Chugwater. The two formations can be separated only by color; the buff color of the Dinwoody gives way to the red of the Chugwater along an irregular surface cutting across rocks lithologically identical. Mention has been made of Lee's belief of an unconformity at this horizon, yet in speaking of this contact in the Wind River Mountains, he says,³³

There is, however, a doubt in his [Lee's] mind as to the exact line of separation between the Dinwoody and the overlying beds.

Although the Dinwoody thins eastward and southward from the type locality, the writer believes that the thinning is not due to post-Dinwoody erosion, but to gradation into the red shales of the basal Chugwater, and that in the area considered in this paper there is no unconformity between the Dinwoody and the Chugwater (Fig. 3).

Age.—The age of the Dinwoody has not been definitely established. When Blackwelder³⁴ named the formation he correlated it with the Woodside shale of Idaho and Utah. The Woodside occupies a position between the top of the Phosphoria, which is surely Permian, and the base of the Thaynes, which is no older than middle Lower Triassic. In addition, the Woodside, in Utah, apparently rests unconformably

³² *Op. cit.*, p. 425.

³³ Willis T. Lee, *op. cit.*, p. 76.

³⁴ *Op. cit.*

on the underlying Phosphoria.³⁵ Consequently, the Woodside seems to be early Lower Triassic in age, and is so considered by the United States Geological Survey.

Except for the sharp change in lithology between the Phosphoria and the Dinwoody, there is no evidence of an unconformity between the formations in the area studied by the writer. If the Dinwoody is Triassic in age, there is no evidence that warping or erosion took place during the interval between the withdrawal of the Permian sea and the encroachment of the Triassic sea. Throughout the area studied, the Dinwoody rests on the uppermost limestone of the Phosphoria, except where the horizon of that limestone is represented by red shale.

In speaking of the Woodside of the Wasatch Mountains of Utah, Mathews says:³⁶

A comparison of the stratigraphic sequence of the rock beds between the Phosphoria and the Pinecrest [Middle Triassic] . . . and the sequence of rocks of the same age between the Productus-limestone and the Ceratite beds of the Salt Range, India, shows a great difference in the thickness of the strata in the two areas. Waagen described the lowermost stratum containing Triassic cephalopods, the *Otoceras* bed, as only a short distance above the Productus-limestone (Carboniferous). And, according to Diener the entire Lower Triassic of the Kashmir Range, Asia, is less than 300 feet thick. It was found that the *Otoceras* bed was less than 60 feet below the *Meekoceras* fauna. Now, since the *Meekoceras* bed is above the top of the Woodside shales in the Fort Douglas area, then the lowest Triassic rocks comparable to the *Otoceras* bed in India must be about 1,000 feet above the top of the Phosphoria formation.

Thus it can be seen that the age of the Woodside formation is problematical. The series probably represents the post-Permian interval but is treated . . . as Lower Triassic.

These facts may explain the anomalous nature of the Dinwoody and the Woodside faunas. Girty³⁷ has pointed out that the fauna of the Woodside is apparently of little value in age determination, but he considers the fauna to be Triassic. H. Glen Walters³⁸ has reported a Dinwoody fauna, which he believes is more closely related to the Permian faunas than to those of the Triassic, and lists the following species.³⁹

³⁵ Asa A. L. Mathews, "Mesozoic Stratigraphy of the Central Wasatch Mountains," *Oberlin College Lab. Bull.*, New Ser., No. 1 (1931), p. 6.

³⁶ *Ibid.*, p. 6.

³⁷ G. H. Girty, in G. R. Mansfield, "Geography, Geology and Mineral Resources of a Portion of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper 152* (1927), pp. 84-85.

³⁸ H. Glen Walters, "The Dinwoody Formation of Western Wyoming," (*abst.*) *Bull. Geol. Soc. America*, Vol. 42, No. 1 (1931), p. 329.

³⁹ Personal communication.

Lingula carbonaria Shumard
Orbiculoides utahensis (Meek)
Myalina congeneris Walcott
Myalina apachesi Marco
Myalina meliniformis Meek and Worthen
Myalina perattenuata Meek and Worthen
Myalina permiana Swallow
Myalina subquadrata Shumard
Myalina sp.
Pleurophorus occidentalis Meek and Hayden
Pleurophorus sp.
Nucula sp.
Alorisma sp.
Eamondia? phosphatica Girty
Bakewellia parva Meek and Hayden
Schizodus wheeleri Swallow
Plazunopsis? sp.
Aviculopecten occidentalis Shumard
Aviculopecten curiocardinalis Hall and Whitfield
Aviculopecten occidaneus Meek
Aviculopecten parvulus Hall and Whitfield
Aviculopecten 2 sp.
Bellerophon sp.

The stratigraphic relations of the Dinwoody to the overlying and underlying beds and the conflicting opinions as to whether the Dinwoody and the Woodside faunas are Permian or Triassic leave the age of the Dinwoody in doubt. Since the Dinwoody is generally assigned to the Triassic, the formation is here treated as though its Triassic age had been definitely established.

Little Medicine tongue of Dinwoody (new name).—The Dinwoody formation thins southeastward along the Wind River Mountains from Dinwoody Canyon to Beaver Creek by replacing overlap of the red Chugwater shale (Fig 3), but a tongue of the formation extends eastward and southward from the Wind River range as a widespread bed of variegated limy sandstone, separated from the Ervay tongue of the Phosphoria by a tongue of red Chugwater shale. It is here proposed to call the variegated limy sandstone the *Little Medicine tongue of the Dinwoody*. The type section is exposed along the north bank of Little Medicine Bow River (locally known as the "Little Medicine") in the Flat Top anticline about eight miles north of the town of Medicine Bow, on the road from Medicine Bow to Casper. The tongue is also exposed in the Rattlesnake Hills, at Alcova, in the Freezeout Hills, in the Ferris and the Seminoe Mountains and at certain localities in the Laramie Basin. The most conspicuous feature of the Little Medicine tongue, throughout its distribution, is its variegated character. Its color varies from tan to gray, olive-green, dove, lavender, maroon and purple. In general, it is a platy, finely laminated, fine-grained, highly calcareous sandstone, but at some localities it is a bed of nearly pure limestone. Invariably the tongue

contains an abundance of small flakes of muscovite, and occasionally it is glauconitic. At many places the upper part is conspicuously ripple marked. The thickness is usually about 10 feet.

The contact of the Little Medicine tongue with the subjacent red shale is gradational. At most places a 2-foot bed of impure gypsum, which seems to be an integral part of the tongue, rests on the variegated portion. The gypsum is usually red or purple and in most places grades up from the underlying variegated limy sandstone. The lithologic character of the Little Medicine tongue at different localities is described in Tables I-VII. At localities at which the Ervay tongue of the Phosphoria is present, the Little Medicine tongue and the tongue of red Chugwater shale below it may be called *Dinwoody, with basal tongue of Chugwater* (Fig. 3). It is not yet known which bed in the type section of the Dinwoody represents the Little Medicine tongue.

TONGUES OF CHUGWATER FORMATION

The original scope of the term, Chugwater, has been discussed. Between Phosphoria and Dinwoody tongues occur red beds, which, in certain regions, comprise distinct stratigraphic units. Thus, in the Laramie Basin, the red shale beneath the Forelle limestone was removed from the base of the Chugwater and considered as a distinct formation—the Satanka shale. The shale is essentially the "Satanka tongue of the Chugwater." The identity of the Satanka shale is limited to the area in which the Forelle limestone can be recognized.

Freezeout tongue of Chugwater (new name).—From the Laramie Basin to the Freezeout Hills, red shales occur between the Forelle limestone and the Little Medicine tongue of the Dinwoody. The name *Freezeout tongue of the Chugwater* is here applied to these red shales. The tongue contains rocks of both Phosphoria and Dinwoody age, but because of the absence of the Ervay tongue, the Phosphoria and the Dinwoody portions can not be separated. The Freezeout tongue contains a few beds of limestone, breccia, and gypsum. Some of these beds may be tongues of the Phosphoria, but most of them are probably local lenticular beds. Because of lithologic variation, the Freezeout tongue can best be defined as comprising the beds between the top of the Forelle limestone and the base of the Little Medicine tongue of the Dinwoody. Such a definition limits the Freezeout tongue to localities at which the Forelle can be definitely recognized. At present, the Forelle has not been identified with certainty, except in the Laramie Basin and northward into the Freezeout Hills.

The name "Embar" is a *nomen nudum* which has been superseded

by the names Phosphoria and Dinwoody. The United States Geological Survey suggests that the use of the name be avoided. If used, the name should be preceded by a dagger to indicate that it is obsolete, thus †Embar.⁴⁰ The use of the name may be avoided by referring to the entire succession of strata from the top of the Tensleep to the top of the Little Medicine tongue of the Dinwoody as the "*intertongued phase of Phosphoria and Dinwoody age.*" There is no intent here to make a formal name. This designation may seem awkward, but until more is known of the exact correlations of the various beds, and especially until the ages of the Phosphoria and the Dinwoody formations are established, it indicates best the true relationship of the beds to which the name "Embar" has been applied.

STRATIGRAPHY OF INTERTONGUED FACIES

The intertonguing of the Phosphoria and the Dinwoody with the Chugwater was studied in the area bounded by the Green Mountains (Fig. 1) on the west, the Rattlesnake Hills on the north, the Freeze-out Hills and the Laramie range on the east, and the Laramie Basin on the south. The intertongued phase, or "Embar," extends over a much larger area, however.

The succession rests unconformably upon the Tensleep sandstone, or upon the Casper formation (Fig. 3), and is characterized by striking lithologic changes both vertically and laterally. The strata are mostly unfossiliferous, but many beds contain fragmentary remains which are rarely well enough preserved to be recognizable. The thickness of the succession ordinarily ranges from 350–400 feet.

The intertongued phase is characterized by several distinctive types of rocks. Breccias are quite abundant and form thin beds, usually less than 5 feet thick, most of which are composed of red shale fragments in a gray lime matrix. Others consist of limestone fragments in a red shale matrix or of red sandstone fragments in a red sandstone matrix. The size of the fragments rarely exceeds 3 inches. The writer has gained the impression that the breccias do not indicate disconformities as some have supposed.⁴¹ The disruption of previously deposited beds by storm waves might produce a rock of this sort. The limited areal extent of the breccias is indicated by exposures around the Flat Top anticline; on its south flank are seven breccia beds within the Freezeout tongue, whereas they are absent on the north flank, 6 miles away.

⁴⁰ Joint Committee on Stratigraphic Nomenclature, "Classification and Nomenclature of Rock Units," *Bull. Geol. Soc. America*, Vol. 44 (1933), p. 434.

⁴¹ Willis T. Lee, *op. cit.*, p. 13.

Many of the limestones are of the "ribbon" variety. These are light-colored, extremely fine-grained, finely laminated limestones. They may be clastic lime muds or chemical precipitates deposited on a portion of the sea floor where there were no mud digesting organisms and where there was not enough agitation of the water to destroy the perfect lamination. Commonly the ribbon limestones have undergone a change that produced "crinkly" limestones in which the lamination planes were warped into small domes and basins from several inches to several feet apart. The amplitude of the folds varies from a fraction of an inch to as much as 6 inches. On outcrops cut nearly at right angles to the bedding the laminae show as wavy lines. The origin of the crinkly structure has been briefly discussed by S. H. Knight,⁴² who believes that the volume of the rock was increased by the addition of magnesium carbonate, for the higher the magnesium content, the greater is the amplitude of the crinkling.

Many of the carbonate beds are dolomites or dolomitic limestones. Numerous writers have pointed out the difficulties of sight identification of dolomites, and Suffel⁴³ has recently called attention to this in his work on the Permian dolomites of Oklahoma. Due to the fact that no microscopic or chemical examinations of the samples collected have been made, the term "limestone" is used here in a broad sense to include calcitic limestones, dolomitic limestones, and dolomites.

The variability of the beds from place to place makes it impossible to generalize the lithology, and for that reason it is necessary to treat each area individually.

LOCALITIES BETWEEN OWL CREEK MOUNTAINS AND FREEZEOUT HILLS

Rattlesnake Hills.—Few geologists have visited the Rattlesnake Hills (Fig. 1), and the little that has been published concerning the stratigraphy of the beds equivalent to the Phosphoria and the Dinwoody in this area has been misleading. Speaking of the Rattlesnake Hills, Darton⁴⁴ says,

... the Tensleep sandstone is separated from the Chugwater red beds by buff shale and thin layers of pure limestone which probably represent the Embar formation.

⁴² S. H. Knight, "Origin of the Crinkly Structure of the Forelle Limestone," (*abst.*) *Jour. Colo.-Wyo. Acad. Sci.*, Vol. 1, No. 4 (1932), p. 32.

⁴³ G. G. Suffel, "Dolomites of Western Oklahoma," *Oklahoma Geol. Survey Bull.* 49 (1930), p. 11.

⁴⁴ N. H. Darton, "Paleozoic and Mesozoic of Central Wyoming," *Bull. Geol. Soc. America*, Vol. 19 (1908), p. 418.

Fossils collected by C. J. Hares in the Rattlesnake Hills were identified by Girty as Phosphoria species.⁴⁵ Information on their exact stratigraphic position, however, has not yet been published.

The impression has been given that the Phosphoria is here lithologically similar to the formation in the Wind River Mountains. However, the Phosphoria and the Dinwoody are represented by about 350 feet of strata of which about 250 feet, about three-quarters, are red shales, which are included tongues of Chugwater. Condit⁴⁶ mentioned that in this locality red shales occur below limestones containing typical Phosphoria fossils, but the significance of this fact seems to have been overlooked by later writers. Table I shows a section of the intertongued phase measured at the head of Casper Creek, just south of Garfield Peak (Figs. 1 and 5).

TABLE I
SECTION MEASURED ALONG CASPER CREEK, RATTLESNAKE
HILLS, NATRONA COUNTY

<i>Column A: thickness of individual beds in feet</i>	<i>A</i>	<i>B</i>
<i>Column B: feet from top of Tensleep sandstone to top of bed</i>		
CHUGWATER: red shale, not measured		
DINWOODY, WITH BASAL TONGUE OF CHUGWATER		
<i>Little Medicine tongue of Dinwoody</i>		
Impure gypsum.....	10	377
Fine-grained, finely laminated, ripple-marked, calcareous sandstone; mostly light greenish gray in color but varies to maroon and purple; weathers into plates and grades into subjacent bed.....	10	367
Thin-bedded, red shaly sandstone with fucoidal markings, similar to those in Dinwoody at Beaver Creek, grading downward into fine-grained, red clay shale.....	58	357
PHOSPHORIA, WITH INCLUDED TONGUES OF CHUGWATER		
<i>Ervay tongue of Phosphoria</i>		
Fine-grained, pink to gray, sandy limestone which contains great amount of laminated blue and gray chert; caps prominent hogback.....	4	299
Lavender, shaly limestone, which contains nodules and laminae of maroon and greenish gray chert and occasional calcite geodes; grades downward into massive, fine-grained, gray limestone with irregular maroon chert nodules. This bed contains great numbers of silicified fossils which are discussed below.....	8	295
Extremely fine-grained, very hard, sublithographic limestone of porcellaneous appearance; no chert present.....	4	287
Purple shale.....	12	283
Fine-grained, finely laminated, gray limestone.....	1.5	271
Red shale.....	3	269.5

⁴⁵ Willis T. Lee, *op. cit.*, p. 54.

⁴⁶ D. D. Condit, "Relations of the Embar and Chugwater Formations in Central Wyoming," *U. S. Geol. Survey Prof. Paper 98* (1916), p. 267.

TABLE I (Cont.)

	<i>Column A: thickness of individual beds in feet</i>	<i>Column B: feet from top of Tensleep sandstone to top of bed</i>	<i>A</i>	<i>B</i>
Laminated, gray chert	0.5	266.5		
Red clay shale	13	266		
Maroon and greenish gray chert, which grades downward into very fine-grained, finely laminated, gray limestone	12	253		
Red clay shale	9	241		
Laminated, bluish gray chert	5	232		
Massive, gray limestone, which contains gray chert laminae	4	227		
Purple shale, which contains laminae of maroon chert	10	223		
Breccia composed of angular, gray limestone fragments in matrix of red sandstone	2	213		
Red shale	15.5	211		
Finely laminated, light gray limestone	2	195.5		
Red shale	49	193.5		
Beds of fine-grained, finely laminated, slightly crinkly limestone, which alternate with four 6-inch beds of gray paper shale	4	144.5		
Ochre shale, 3 feet thick, which grades downward into dense, thin-bedded, finely laminated, grayish white limestone	8	140.5		
Red, flaky shale	60	132.5		
Sybille tongue of <i>Phosphoria</i>				
Dense, white limestone with numerous black specks of dendrite	5	72.5		
Purple, limy sandstone, which grades downward into purple and white sandstone containing numerous small cavities, occasional calcite geodes and <i>Plagioglypta?</i> sp	7.5	67.5		
Covered portion; soil derived mainly from red shale	40	60		
Conglomerate composed of rounded cobbles up to 6 inches in diameter; mainly covered, and contact with the Tensleep is obscured	20±	20±		
TENSLEEP SANDSTONE: cross-laminated sandstone; not measured				
TOTAL	377±			

The conglomerate composed of cobbles of chert, sandstone, and quartzite at the base of the section is deserving of further study. Where seen it was not well exposed and its relations to the overlying beds and to the underlying Tensleep could not be ascertained. However, it is a rock type foreign to the Tensleep and may be considered as the basal conglomerate of the Phosphoria. A basal conglomerate occurs farther south at Alcova. It differs from the conglomerate at Casper Creek in that it is not a true conglomerate, but consists of sporadic blocks of Tensleep sandstone in a sandstone bed. At Ervay, about 10 miles northwest of the Casper Creek locality, there is no evidence of such a conglomerate, the basal member of the Phosphoria being a 60-foot bed of limestone. At present the relations of these basal beds to each other are not understood.

The Sybille tongue, as usual, carries calcite geodes and *Plagioglypta?* sp. The bed of breccia is similar to the breccias so common in the red-bed facies farther south.

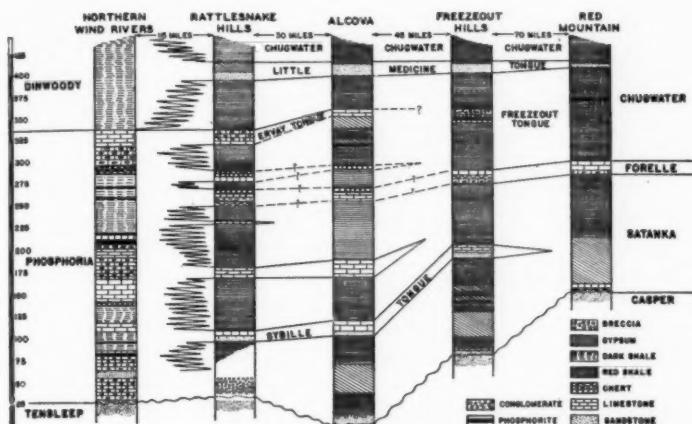


FIG. 5.—Correlation chart of sections between northern end of Wind River Mountains and southern end of Laramie Basin.

The following fossils were collected from the Ervay tongue at the head of Casper Creek and along Poison Spider Creek, south of Garfield Peak.

	c*
Bryozoans (many species).....	c
<i>Punctospirifer pulchra</i> (Meek).....	c
<i>Punctospirifer</i> aff. <i>P. kentuckensis</i> (Shumard).....	s
<i>Composita</i> cf. <i>C. mexicana</i> (Hall).....	c
<i>Derbyia</i> aff. <i>D. plicatella</i> Waagen.....	a
<i>Tentaculites</i> sp.....	r
<i>Plagioglypta?</i> sp. (small).....	r
<i>Myalina</i> sp. (large).....	c
<i>Myalina</i> aff. <i>M. perattenuata</i> Meek and Hayden.....	r
<i>Pleurophorus</i> <i>pricei</i> Branson.....	s
<i>Pleurophorus</i> (four species).....	s
<i>Leda obesa</i> (White).....	s
<i>Cyrtorosta?</i> sp.....	r
<i>Aviculopecten</i> sp.....	r
<i>Deltopecten vanvleeti</i> (Beede).....	r
<i>Parallelododon</i> aff. <i>P. tenuistrigatus</i> (Meek and Worthen).....	r
<i>Edmondia?</i> sp.....	r
<i>Schizodus</i> cf. <i>S. wheeleri</i> (Swallow).....	c
<i>Schizodus?</i> sp. (large).....	c
<i>Schizodus</i> sp. (small).....	c
<i>Pinna peracuta</i> Shumard.....	a
<i>Euphemus subpilosus</i> (White).....	c
<i>Bellerophon</i> sp.....	c
Gastropod (high-spired form).....	r
<i>Coelogasteroceras thomasi</i> Miller and Cline.....	r
<i>Coloceras?</i> sp.....	r
Denticles, probably from the spine of an elasmobranch.....	r

* In the faunal lists relative abundance of specimens is indicated as follows. a, abundant; c, common; s, scarce; r, rare.

This faunule, which serves as a basis for the correlation of the Ervay tongue with the top limestone of the Phosphoria, contains many species which are common in, or confined to, the upper limestone member of the Phosphoria of the Wind River Mountains. This limestone has been referred to by several geologists as the "Upper Bryozoan limestone," and its fauna has been called the "*Spiriferina pulchra* fauna," because of the abundance of bryozoans and of *Punctospirifer pulchra*. These fossils occur in the Ervay tongue in considerable abundance. *Pleurophorus pricei*, *Euphemus subpilosus* and *Deltopecten vanvleeti* are confined to the top limestone of the Phosphoria in the Wind River Mountains. Many other species found in the Ervay tongue are confined to the upper portion of the Phosphoria.

In different localities different species occur in varying degrees of abundance. On Casper Creek *Derbyia* aff. *D. plicatella* occurs in extreme abundance, but on the north, at Ervay, and on the south along Poison Spider Creek, the species is quite rare. *Punctospirifer* aff. *P. kentuckiensis* is the most abundant species along Poison Spider Creek, is rare along Casper Creek, and is absent at Ervay. At Ervay, *Myalina* and *Bellerophon* are the most abundant fossils. *Euphemus subpilosus* is relatively common at all three localities.

The species of *Derbyia* is comparable to *Derbyia plicatella* Waagen in that both are characterized by radial plications. The Rattlesnake Hills specimens have the precise internal structure of *Derbyia*, i.e., a rather high ventral septum and dental lamellae which are almost obsolescent, but differ from typical members of the genus in the presence of rounded plications upon which are superimposed finer striations. Similar plicated specimens of *Derbyia* are found in the upper part of the Phosphoria formation in the Wind River Mountains.

The productids are perhaps the most abundant brachiopods, both in number of species and in number of specimens, in the Phosphoria fauna of western Wyoming, but are represented in the top limestone by only one species, *Aulosteges hispidus*. No productids are present in the Ervay tongue faunule. The occurrence of *Tentaculites* is unusual, for this genus apparently has not heretofore been reported in North America from rocks younger than the Devonian.

Another section, which differs little from that on Casper Creek, was measured at Ervay. The total thickness of the Phosphoria and the Dinwoody with included tongues of Chugwater is 388 feet. The basal member, previously mentioned, is a fine-grained, thin-bedded, white, sandy limestone containing scattered calcite geodes. Near the top it becomes dense and brittle and contains a few layers of brown chert. The middle portion of the section consists mainly of red shale,

but is largely covered. The main dip slope is formed by a chert member, 25 feet stratigraphically below the Ervay tongue. The chert member consists of 57 feet of gray and lavender, cherty limestones and beds of pure chert. In the middle portion of the member were found *Punctospirifer pulchra* and *Orbiculoides cf. O. utahensis*. The Ervay tongue is here much less fossiliferous than at Casper Creek. It was only after an extended search that the following fossils were collected.

<i>Derbyia aff. D. plicatella</i> Waagen.....	r
<i>Leda obesa</i> (White)?.....	s
<i>Myalina</i> sp. (large).....	c
<i>Myalina</i> sp. (small).....	c
Pelecypod, indeterminable.....	r
<i>Euphemus subpapillosus</i> (White).....	c
<i>Bellerophon</i> sp.....	c

Alcova.—In speaking of the region around Alcova, Lee⁴⁷ made the following statement.

The writer . . . believes that such beds of Phosphoria and Dinwoody age as may have existed here were eroded away before the deposition of the red beds, and that the geologic time denoted by these formations is here represented by the unconformity that separates the Chugwater red beds from the underlying Casper formation.

A section (Table II) measured by the writer northeast of Alcova Cut (Fig. 5) shows representatives of the Phosphoria and the Dinwoody.

TABLE II
SECTION MEASURED NEAR ALCOVA, NATRONA COUNTY

Column A: thickness of individual beds in feet	A	B
Column B: feet from top of Tensleep sandstone to top of bed		
<hr/>		
CHUGWATER: red shale, not measured.		
<hr/>		
DINWOODY, WITH BASAL TONGUE OF CHUGWATER		
<i>Little Medicine tongue of Dinwoody</i>		
Laminated red gypsum.....	2.5	450.3
Finely laminated, thin-bedded, ripple-marked purplish to greenish gray, calcareous sandstone weathering brown in upper portion; grades downward into red shaly sandstone.....	14	447.8
Fine-grained, thin-bedded, platy, red sandstone grading downward into red sandy shale.....	37.5	433.8
<hr/>		
PHOSPHORIA, WITH INCLUDED TONGUES OF CHUGWATER		
<i>Ervay tongue of Phosphoria</i>		
Extremely fine-grained, massive, conspicuously mottled gray and lavender limestone containing a few unrecognizable fossils.....	8	396.3
<hr/>		

⁴⁷ *Op. cit.*, p. 50.

TABLE II (Cont.)

<i>Column A: thickness of individual beds in feet</i>	<i>Column B: feet from top of Tensleep sandstone to top of bed</i>	<i>A</i>	<i>B</i>
Alternating beds of red shale and gypsum.....	55	388.3	
Chert member; fine-grained, finely laminated dark gray limestones interbedded with brittle, siliceous black paper shale containing laminae and nodules of light blue chalcedony.....	5	333.3	
Interbedded gypsum and gray flaky shales.....	19.5	328.3	
Chert member; limy, dark gray paper shale with laminae of bluish gray chalcedony.....	5	308.8	
Limestone and gypsum occurring in different proportions in different localities; usually some breccias present, which are composed of angular clay fragments in gray lime matrix.....	9	303.8	
Ten feet of purple sandstone grading downward into brick-red sandy shale containing numerous circular white spots.....	90	294.8	
Finely laminated, gray limestones, some of crinkled variety and others partially replaced by gypsum, interbedded with thin gray shales; some brown chert present. In limestone near middle are found many poorly preserved specimens of following fossils: <i>Myalina permiana</i> Swallow, <i>Pinna</i> cf. <i>P. peracuta</i> Shumard, <i>Pleurophorus</i> sp., high-spired gastropods, several species.....	22.2	204.8	
Flaky red shale with numerous small oval cream-colored spots	54.7	182.6	
<i>Syllite tongue of Phosphoria</i>			
Alternating gray sandstones and gray limestones, upper part of which contains abundant calcite or quartz geodes and poorly preserved specimens of <i>Plagioglypta?</i> sp.....	17.7	127.9	
Fine-grained, flaky, brick-red shale.....	35	110.2	
Gypsum.....	37	75.2	
Red shale with several thin, porous, gypsiferous limestones.....	25	38.2	
Massive, medium-grained, tan sandstone with red streaks. In upper portion are sporadic angular blocks of Tensleep sandstone as large as 3 feet. The bed abruptly truncates cross-lamination of underlying Tensleep.....	13.2	13.2	
TENSLEEP SANDSTONE: not measured.			
TOTAL.....		447.8	

The blocks of Tensleep sandstone in the upper part of the basal bed provide additional evidence of the unconformity which separates the Tensleep from the Phosphoria. It has been pointed out that with an advancing shore line, there may be deposited

... a thin layer of sediments derived from the residual soil, and these will be succeeded by coarser sediments . . . derived from erosion of bed rock.⁴⁸

It appears that the Phosphoria sea advanced over a surface composed of weathered Tensleep sandstone, and that wave erosion on bed rock dislocated the large, angular blocks of Tensleep which were incorporated in the basal bed of the Phosphoria.

The beds representing the Phosphoria at Alcova differ from those in the Rattlesnake Hills mainly in the smaller amount of chert, in the occurrence of thick gypsum beds near the base, and in the presence of more abundant breccias and gypsiferous limestones.

⁴⁸ W. H. Twenhofel, *Treatise on Sedimentation* (1932), p. 144.

The writer believes, because of stratigraphic sequence and lithologic similarity, that the 10-foot bed of mottled limestone represents the Ervay tongue of the Rattlesnake Hills, which in turn represents the top of the Phosphoria of the Wind River range. The bed here is apparently unfossiliferous, but this is of little significance, for in the Rattlesnake Hills the Ervay tongue is extremely fossiliferous in some localities, and in others, a few miles away, contains few fossils.

The Little Medicine tongue and the subjacent, red, sandy shale, which represent the Dinwoody, are here lithologically typical and have their usual thickness.

Freezeout Hills and Flat Top anticline.—The Freezeout Hills are located at the junction of a line of measured sections extending northwest from the southern end of the Laramie Basin to the Rattlesnake Hills (Fig. 1) and another line extending westward from the Freezeout Hills to the southern end of the Wind River Mountains. Consequently, sections in the Freezeout Hills occupy a key position for correlation. Lee⁴⁹ has said:

There are no rocks in this region that can be confidently correlated with the Embar formation of the Wind River Mountains and Owl Creek Mountains—that is, with the Phosphoria and Dinwoody formations. However, the beds which Condit regarded as the eastern representatives of the Embar, and which oil operators in Wyoming call Embar, are typically developed in the lower part of the "Red Beds" near Difficulty.

A section measured by the writer at the Ellis Ranch on Difficulty Creek is shown in Table III in considerable detail.

A section measured at Flat Top anticline, about 12 miles southeast of Difficulty, differs only a little from the Difficulty section. In neither of these localities is the Ervay tongue present, and therefore it is impossible to separate the Phosphoria from the Dinwoody. Here, however, the Forelle limestone may be differentiated, and strata of both Phosphoria and Dinwoody age occurring above the Forelle and below the Little Medicine tongue are placed together to form the Freezeout tongue of the Chugwater formation. The beds below the Forelle represent the Satanka shale of the Laramie Basin.

The basal bed of the section appears to consist of reworked sandy material derived from the Tensleep sandstone. The limy beds below the 70 feet of red shale in the upper part of the Satanka constitute the Sybille tongue. The gypsum beds below the tongue are known to be lenticular and probably do not represent Phosphoria tongues, although they are of that age.

The Forelle may be traced almost continuously from here into the

⁴⁹ *Op. cit.*, p. 71.

TABLE III
SECTION MEASURED NEAR DIFFICULTY POST OFFICE, FREEZEOUT
HILLS, CARBON COUNTY

	<i>Column A: thickness of individual beds in feet</i>	<i>Column B: feet from top of Tensleep sandstone to top of bed</i>	<i>A</i>	<i>B</i>
CHUGWATER: red shale, not measured				
RED-BED FACIES OF THE PHOSPHORIA AND DINWOODY FORMATIONS				
<i>Little Medicine tongue of Dinwoody</i>				
Variegated sandy and shaly limestone, predominantly lavender in color but varying to purple, dove, olive and gray; not entirely exposed. In the Flat Top uplift is capped by 2 feet of porous, gypsiferous limestone and breccia.....	10			327.2±
<i>Freezeout tongue of Chugwater</i>				
Covered portion, probably mostly red shale; in Flat Top uplift this portion consists of red shales and thin breccias. Exact thickness not measurable.....	20±			317.2±
Porous, impure, massive gray limestone.....	2			297.2
Variegated, red and olive, gypsiferous shale.....	16.5			295.2
Gypsum.....	3			278.7
Breccia; angular masses of gray limestone in red shale matrix	6			275.7
Breccia; angular fragments of red shale and crinkled limestone in gray lime matrix.....	4			269.7
Red shale.....	2			265.7
Breccia; angular fragments of crinkled limestone and red shale in gray lime matrix grading downward into crinkly limestone.....	2			263.7
Gray shale.....	1			261.7
Breccia; red, sandy shale fragments in matrix of same character.....	2			260.7
Breccia; red shale fragments in lime matrix.....	0.2			258.7
Fine-grained, finely laminated, slightly crinkled white limestone.....	1.5			258.5
Red sandy shale with numerous circular gray spots.....	50			257
<i>Forelle limestone</i>				
Cream-colored, porous, gypsiferous crinkly limestone.....	2			207
Shale, upper 2 feet gray, lower foot red.....	3			205
Finely laminated, dark gray, siliceous shale.....	5			202
Gray, crinkly limestone containing dark gray and black chert	4			197
<i>Satanka shale</i>				
Red sandy shale containing numerous gray spots. Very sandy in middle. Ten feet of leached, olive shale at base.....	70			193
<i>Sybille tongue of Phosphoria</i>				
Sugary, coarse-grained limestone. Upper portion contains numerous gray, irregularly shaped chert nodules.....	8			123
Gray shaly sandstone.....	2.5			115
Gray sandstone containing numerous small calcite geodes.	2			112.5
Gray sandstone grading downward into gray sandy shale..	5			110.5
Flaky red shale with numerous gray spots.....	30			105.5
Gypsum.....	8			75.5
Red shale with thin gypsum beds.....	21			67.5
Gypsum.....	30			46.5
Olive sandy shale.....	12			16.5
Finely laminated pink and white limestone.....	1.5			4.5
Soft, saccharoidal sandstone and very fine-grained, sandy material. Strikingly different from subjacent Tensleep sandstone.....	3			3
TENSLEEP SANDSTONE: not measured.				327.2±
TOTAL.....				327.2±

Laramie Basin. It is not truly typical in the Difficulty section, but in the Flat Top anticline is lithologically identical with the Forelle at the type locality in the Laramie Basin.

The Freezeout tongue consists of interbedded red shale, numerous breccias and crinkly limestone, and a little gypsum. Some of the limestone, gypsum and breccia beds are lenticular; possibly none represent Phosphoria tongues, although one of them may be an edge of the Ervay tongue. The Little Medicine tongue is readily recognized in both localities.

LOCALITIES BETWEEN SOUTHERN END OF WIND RIVER MOUNTAINS AND FREEZE-OUT HILLS

A series of sections was measured in the region between the southern end of the Wind River Mountains and the Freezeout Hills. Mention has previously been made of the occurrence of typical Phosphoria at Ice Slough (p. 1661).

Green Mountains.—The next exposed section eastward from Ice Slough is located in the Green Mountains. Here the beds are highly deformed and, where the section was measured, are upside down and dip 50°. Such deformation has undoubtedly affected the thicknesses of the less competent members, but the measurements obtained do not seem to be greatly different from those that might be expected (Table IV).

TABLE IV
SECTION MEASURED ON WEST FORK OF COTTONWOOD CREEK, GREEN MOUNTAINS,
FREMONT COUNTY

Column A : thickness of individual beds in feet	Column B : feet from top of Tensleep sandstone to top of bed	A	B
<hr/>			
CHUGWATER: red shale, not measured.			
<hr/>			
DINWOODY			
Thin-bedded, oil-saturated sandstone, which weathers brown.			
Upper part is ripple marked and contains fucoidal markings.	41	336.7	
Soft tan shale	13	295.7	
Red, pink, and ochre shale	10	282.7	
<hr/>			
PHOSPHORIA, WITH INCLUDED TONGUES OF CHUGWATER			
<i>Ervay tongue of Phosphoria</i>			
Brown sandstone containing much chert and poorly preserved fossils; <i>Derbyia</i> aff. <i>D. plicatella</i> Waagen, <i>Hustedia</i> sp., <i>Punctospirifer pulchra</i> (Meek), <i>Polypora?</i> sp.	9	272.7	
Tan sandy shale	6	263.7	
Gray, fossiliferous limestone with fragmentary unrecognizable fossils	2	257.7	
Tan shaly sandstone	5	255.7	
Lavender shaly limestone	1.6	250.7	
Light gray siliceous shale	0.5	249.1	

TABLE IV (Cont.)

Tan cherty sandstone.....	2.2	248.6
Brown chert in beds 2-6 inches thick.....	3.6	246.4
Tan sandstone containing chert nodules.....	3	242.8
Red sandstone.....	0.5	239.8
Pink shaly limestone with irregular, gray chert nodules.....	3.5	239.3
Pure gray chert; weathers into angular fragments because of its brecciated condition.....	25	235.8
Red sandy shale with ramifying, harder, red sandy aggregates.	127	210.8
<i>Sybille tongue of Phosphoria</i>		
Hard, dense, siliceous, gray limestone with small, angular, gray chert masses.....	0.6	83.8
Thick-bedded, lavender limestone with individual beds ranging from 9 inches to 20 inches in thickness, some slightly shaly, contains numerous calcite geodes; weathers brown.....	6.7	83.2
Lavender and maroon shaly sandstone; not well exposed.....	7	76.5
Dense, lavender limestone.....	1.2	69.5
Hard, dense, white limestone with a few calcite geodes.....	3.3	68.3
Red sandy shale with ramifying aggregates of red sandstone.....	35	65
Very dense, very hard, siliceous, gray limestone with occasional lamina or nodule of gray chert.....	25	30
Red shale with unconsolidated, fine sand resting directly on Tensleep sandstone and truncating its cross-lamination.....	5	5
TENSLEEP SANDSTONE: not measured.....		
TOTAL.....	336.7	

The Sybille tongue carries the usual geodes, but no fossils were found in the bed at this locality. The upper part of the Phosphoria is very cherty and is similar to the upper part of the formation in the Rattlesnake Hills. The uppermost 9-foot bed of sandstone is probably

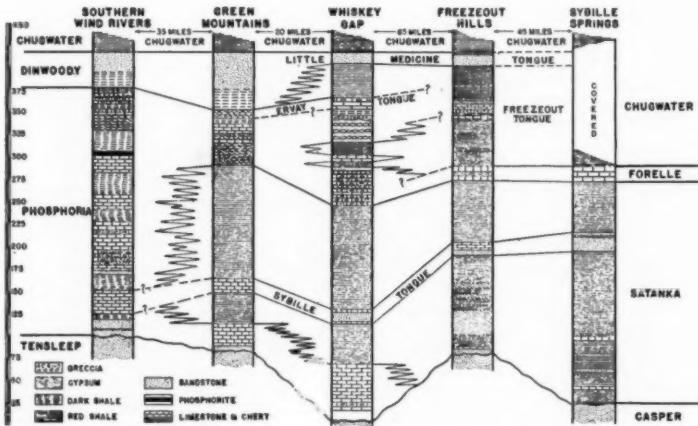


FIG. 6.—Correlation chart of sections between southern end of Wind River Mountains and northern end of Laramie Basin.

the Ervay tongue, for it occupies the correct stratigraphic position and carries a similar fauna.

The chert beds here are all highly brecciated and consist of angular fragments of chert in a siliceous matrix. The brecciation is undoubtedly the result of proximity to a large thrust fault along which these beds have been overturned. G. R. Mansfield has examined a specimen of the chert and believes that the brecciation is similar to that produced in the Rex chert member of the Phosphoria formation along the Bannock overthrust in Idaho.⁵⁰ This sort of breccia should not be confused with the calcareous breccias so prevalent in the red beds, for the two have distinctly different origins.

The upper sandy portion of the Dinwoody is similar in lithology to the Dinwoody along the southern end of the Wind River range, but the lower shaly portion contains red beds in its base. East of the Green Mountains the upper sandstone forms the Little Medicine tongue of the Dinwoody. The subjacent shales grade into the red sandy shale between the Little Medicine tongue and the Ervay tongue of the Phosphoria.

Numerous changes take place in the intertongued phase of the Phosphoria between the Green Mountains and Whiskey Gap. The intervening area is covered with Tertiary beds, however, and no intermediate sections can be measured.

Whiskey Gap.—The strata that have been called "Embar" by oil geologists are conspicuously exposed in the vicinity of Whiskey Gap. The beds here stand vertically, or are overturned, and because the resistant Tensleep sandstone forms a high ridge, the softer Phosphoria and Dinwoody representatives are partly covered with detritus. However, a nearly complete section can be compiled between Whiskey Gap and Muddy Gap, several miles farther west. Because of the rapid alternation of beds lithologically different it is impracticable to reproduce the section here in all its detail (Table V).

The section bears a strong resemblance to the section at Ervay in the Rattlesnake Hills in the abundance of chert in the upper portion and in the presence of a thick basal limestone.

It is believed that the irregular surface below the breccia near the top of the Phosphoria does not represent an unconformity. Although the bed contains fragments of the underlying beds in its base, these fragments have not been moved far (Fig. 7), and the feature can perhaps be attributed to contemporaneous erosion brought about by shifting marine currents. A considerable break may be indicated, how-

⁵⁰ Personal communication.

TABLE V
SECTION MEASURED BETWEEN WHISKEY GAP AND MUDDY GAP, CARBON COUNTY

<i>Column A: thickness of individual beds in feet</i>	<i>Column B: feet from top of Tensleep sandstone to top of bed</i>	A	B
CHUGWATER: red shale, not measured.			
DINWOODY, WITH BASAL TONGUE OF CHUGWATER			
<i>Little Medicine tongue of Dinwoody</i>			
Finely laminated red limestones and red shales.....	8	426	
Red shale.....	30	418	
Flaky, gray shale.....	5	388	
PHOSPHORIA, WITH INCLUDED TONGUES OF CHUGWATER			
<i>Ervay tongue of Phosphoria</i>			
Gray limestones, cherty in upper portion.....	14	383	
Flaky gray and tan shale.....	6	369	
Breccia composed of angular fragments of chert, limestone and sandstone; rests on irregular surface and contains fragments of underlying bed in its basal part (Fig. 7).....	3	363	
Thick-bedded gray sandstone; contains much chert.....	25	360	
Red shale.....	14	335	
Gray limestone with nodules and laminae of gray and red chert.	7	321	
Red shale.....	6	314	
Breccia composed of angular fragments of chert and lavender ribbon limestone in gray lime matrix.....	3	308	
Dense, light gray limestone with abundance of chert occurring as nodules and laminae; upper part sandy.....	28	305	
Finely laminated, fine-grained, lavender sandy limestone containing chert nodules.....	12	277	
Brick-red sandy shale.....	115	265	
<i>Sybille tongue of Phosphoria</i>			
Dense, white limestone.....	2	150	
Purple shaly sandstone seamed with occasional chalcedony veins along bedding. Contains poorly preserved specimens of <i>Euphemus carbonarius</i> (Cox), <i>Bucanopsis</i> cf. <i>B. meekiana</i> (Swallow) <i>Bellerophon?</i> sp., <i>Nucula?</i> sp., and numerous fragments of unrecognizable fossils.....	10	148	
White limestone with small black specks of dendrite.....	2	138	
Red shales, thin sandstones, and thin limestones.....	52	136	
Thick-bedded gray limestone; portions seem to be made up of macerated fragments of fossils and other portions are composed of algae (?); small amount of laminated chert near base.....	64	84	
Covered portion.....	20	20	
TENSLEEP SANDSTONE: not measured.			
TOTAL.....		426	

ever, but until further knowledge is available it is impossible to judge the time value of this erosion surface.

The upper 14-foot bed of cherty limestone probably represents the Ervay tongue of the Phosphoria. Although it is unfossiliferous, it lies in the same stratigraphic position as the Ervay tongue in the Rattlesnake Hills, i.e., below the basal red shale of the Dinwoody and above the main chert member of the Phosphoria. The Little Medicine

tongue of the Dinwoody is present, as in all other sections, but is completely red in color.

Black Canyon.—The section on the east side of Black Canyon, where the North Platte River cuts through the Seminoe Mountains, is not well exposed, and consequently a detailed section could not be measured. From Whiskey Gap eastward toward Black Canyon the most outstanding change in the Phosphoria is the disappearance of the thick chert beds and the cherty limestones. A bed of lavender

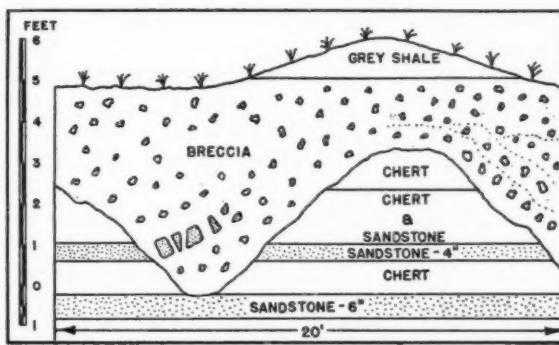


FIG. 7.—Sketch of erosion surface within beds of Phosphoria age at Whiskey Gap.

limestone 20 feet thick near the top of the Black Canyon section probably does not represent the Ervay tongue, although it occupies the same stratigraphic position. It is lithologically more like the lavender limestones below the Ervay tongue at Whiskey Gap and at Ervay. Furthermore, its thickness seems too great, for here the Ervay tongue should be thinner than it is at localities on the west and north of Black Canyon. It is believed that the Ervay tongue thins out between Whiskey Gap and Black Canyon and between Alcova and Black Canyon, and that the lavender limestone at Black Canyon represents beds below the Ervay tongue at Whiskey Gap. If this be true, the basal portion of the red shale above the lavender limestone and below the Little Medicine tongue is of Phosphoria age. Beds representing the Forelle limestone have not been recognized at Black Canyon, but eastward toward the Freezeout Hills, beds lithologically typical of the Forelle appear. The Little Medicine tongue of the Dinwoody is readily recognizable at Black Canyon and continues eastward into the Freezeout Hills with almost no change in lithology or in thickness.

LOCALITIES IN LARAMIE BASIN

The Satanka shale, the Forelle limestone, the Freezeout tongue of the Chugwater, and the Little Medicine tongue of the Dinwoody are probably everywhere present in the Laramie Basin, but there is no place between the Flat Top anticline and Red Mountain where all are exposed in the same section. The soft shales of the Satanka and the Chugwater are poorly exposed along the west flank of the Laramie Mountains, and it is impossible to measure detailed sections of the Satanka or to find the Little Medicine tongue. The Forelle is fairly well exposed in most places. Therefore, in the Laramie Basin, it is most convenient to apply the name, Chugwater, to all the red beds between the Forelle and the Jelm formation (Upper Triassic). The name, thus applied, includes the Freezeout and the Little Medicine tongues (Figs. 5 and 6).

Along the west flank of the Laramie Mountains the Casper formation consists of a cyclical sequence of cross-laminated sandstones grading upward into fossiliferous limestones. Each limestone was subjected to erosion before the deposition of each overlying sandstone.⁵¹ It is not possible at present to locate the pre-Satanka erosion surface because of confusion with the intra-Casper erosion surfaces. For this reason some beds now included in the Casper may properly belong in the Satanka. The writer has placed the base of the Satanka at the horizon above which red shales predominate and above which no festoon⁵² cross-laminated sandstones are found.

In the Centennial Valley, along the east side of the Medicine Bow Mountains, the Casper contains festoon cross-laminated sandstones similar to the Tensleep sandstones. The contact of the red shale of the Satanka and the upper cream-colored sandstone of the Casper is an undulating surface with 5 or 6 feet of relief. The exact relation of the Casper to the Tensleep is, however, still an open problem. The writer believes that the unconformity between the Casper and the Satanka is the same as the one separating the Tensleep from the intertongued phase of the Phosphoria in central Wyoming and the Tensleep from the Phosphoria farther west.

The Satanka consists almost wholly of red shale, but a few thin beds of other sorts are intercalated throughout. Gypsum is present near the base of the formation, especially in the southern part of the Laramie Basin. The thickness of the Satanka varies considerably, but averages about 250 feet. The Forelle is almost everywhere divisible

⁵¹ S. H. Knight, "The Fountain and Casper Formations of the Laramie Basin," *Univ. of Wyoming Pub. in Science, Geology*, Vol. 1, No. 1 (1929), p. 53.

⁵² *Ibid.*

into (1) a basal gray limestone, which is usually crinkly and is dolomitic or gypsiferous at various localities; (2) a middle lavender, platy limestone, generally fine-grained, and finely laminated, and (3) an upper gray limestone, usually crinkly and dolomitic or gypsiferous. The Forelle has been reported to be fossiliferous by Darton and Siebenthal,⁵³ but the writer has not found fossils that are identifiable. Fragments of fossils abound, but complete specimens have been obliterated by changes which produced the crinkly structure, by dolomitization, or by gypsum replacement. The average thickness of the Forelle is about 18 feet.

The ages of the Satanka and the Forelle have never been definitely determined. W. C. Knight⁵⁴ believed that the beds which now comprise the Satanka and the Forelle were of Permian age. Darton and Siebenthal,⁵⁵ however, treated the formations as Pennsylvanian. Lee⁵⁶ made no definite statements regarding the age of the Satanka and the Forelle, but in his graphic sections placed the Phosphoria, the Satanka and the Forelle in the Permian. He classed the Dinwoody as Triassic and said he believed it "to thin out toward the east and lie unconformably beneath Satanka shale." He thus placed the Triassic rocks below the Permian rocks, yet he correlated the Satanka and the Forelle with the "Embar," which he placed above the Dinwoody. It is difficult to decide whether Lee considered the Satanka and the Forelle as Permian or Triassic.

The formations, however, were undoubtedly deposited during Phosphoria time, and the determination of their age necessarily rests upon the determination of the correct age of the Phosphoria. If the Phosphoria is considered wholly Middle Permian, the age of the Satanka and the Forelle must also be Middle Permian. The fauna of the Satanka is of little value for age determination.

In order to demonstrate that all the beds present in the "Embar" of central Wyoming are represented in the Laramie Basin by the Satanka, the Forelle, and the lower part of the Chugwater, the few localities in the Laramie Basin where the rocks are well exposed are discussed below.

Como Bluff.—North of Como Bluff, along Rock Creek, the Little Medicine tongue and a portion of the subjacent Freezeout tongue are exposed. The Little Medicine tongue has the same lithologic character

⁵³ *Op. cit.*

⁵⁴ W. C. Knight, "The Laramie Plains Red Beds and Their Age," *Jour. Geol.*, Vol. 10, No. 4 (1902).

⁵⁵ *Op. cit.*

⁵⁶ *Op. cit.*

and thickness as in the Flat Top anticline. The red shales of the exposed portion of the Freezeout tongue contain several beds of gypsum.

Boswell Springs.—In the vicinity of Boswell Springs the Satanka and the Forelle are present, although the Satanka is completely covered. A short distance farther southeast the Little Medicine tongue is exposed above the red shales and gypsum of the Freezeout tongue, but it is impossible to measure the stratigraphic interval between the Little Medicine tongue and the Forelle.

Sybille Springs anticline.—The Satanka is poorly exposed, but a nearly complete section can be compiled. The Forelle is exposed in several places, but all the beds above it are covered. The formations are shown in Table VI.

TABLE VI
SECTION MEASURED AT SYBILLE SPRINGS ANTICLINE, ALBANY COUNTY

	Column A : thickness of individual beds in feet	Column B : feet from top of Tensleep sandstone to top of bed	A	B
CHUGWATER (including Little Medicine and Freezeout tongues): covered.				
FORELLE				
Crinkly ribbon limestone.....	4	278		
Red shale.....	5	274		
Crinkly ribbon limestone.....	2	269		
Purple shale.....	4	267		
Crinkly ribbon limestone.....	3	263		
SATANKA				
Red shale, not well exposed.....	55	260		
<i>Sybille tongue of Phosphoria</i>				
Buff limy sandstone mottled with pink and containing calcite geodes and chert.....	21	205		
Red shale, with a few thin beds of buff sandstone, gray porous limestone, and pink and gray ribbon limestone.....	184	184		
CASPER: not measured.				
TOTAL		278		

The lithologic character of the Sybille tongue has been discussed in its definition (p. 1664). Its fauna consists of the following incompletely silicified specimens.

<i>Aviculopecten</i> sp. undescribed.....	r
Small pelecypod.....	r
<i>Plagiostyptal</i> sp.....	c
<i>Euphemus carbonarius</i> (Cox).....	r
<i>Bellerophon?</i> sp.....	r
<i>Strophostylus?</i> sp.....	r

Fragments of other species exist, and further collecting will undoubtedly add to this fauna.

The Forelle is typical in lithologic character. The exposures of the

Satanka and the Forelle from this point southward are poor, and the next available complete section is on the southern edge of the Laramie Basin, at Red Mountain.

Forelle Siding.—The Forelle is poorly exposed at its type locality south of Laramie. The lower limestone is made up principally of small fragments of fossils. Overlying it is a platy, purple limestone, above which is a porous gypsumiferous limestone. It is impossible to discover whether this is the top of the Forelle.

Satanka Siding.—At the type section of the Satanka the exposures are such that one can determine only that the formation consists predominantly of red shale.

Red Mountain.—Misstatements as to the stratigraphy of the Satanka, the Forelle, and the lower part of the Chugwater at Red Mountain have become almost hopelessly entangled in the geologic literature. A fossiliferous limestone, which in places is a breccia, was mistaken by Darton and Siebenthal⁵⁷ for the Forelle. Since the limestone occurs only three feet above the top of the Casper, they assumed that the Satanka was absent at Red Mountain. Lee had noted a conspicuous breccia which occurs above the Forelle at various localities and, because of the similarity between this breccia and the one in the base of the Satanka at Red Mountain he decided that the two were the same, and says:⁵⁸

If the fossiliferous breccia at Red Mountain proves to be the equivalent of the similar limestone breccia of neighboring localities, the unconformity beneath it must represent Forelle, Satanka and Phosphoria time . . . No purple shale that can be called Satanka was found, nor any limestone which the writer would call Forelle.

It has been pointed out that a number of different beds of breccia occur in different localities and that these beds do not represent a single horizon. The section at Red Mountain is interpreted by the writer as shown in Table VII.

The red shale of the Satanka is typical in lithologic character, but the gypsum in the base is absent at the type locality. Gypsum, however, is common in the basal portion of the intertongued phase of the Phosphoria at localities north of the Laramie Basin. The Sybille tongue is not present at Red Mountain.

The basal fossiliferous limestone of the Satanka is a variable bed. In some places it is a breccia and in others it has been replaced to various degrees by gypsum. Changes taking place within a few tens of feet considerably alter the lithologic sequence of the basal beds. A

⁵⁷ *Op. cit.*

⁵⁸ Willis T. Lee, *op. cit.*, p. 69.

TABLE VII
SECTION MEASURED ON NORTHWEST FACE OF RED MOUNTAIN

	<i>Column A : thickness of individual beds in feet</i>	<i>Column B : feet from top of Tensleep sandstone to top of bed</i>	<i>A</i>	<i>B</i>
CHUGWATER				
Red shale and sandstone, not measured				
<i>Little Medicine tongue of Dinwoody</i>				
Purple, finely laminated gypsum, grading downward into sub-jacent bed.....	2	261.8		
Very fine-grained, limy sandstone, mostly red, but with greenish laminae; finely laminated throughout; gypsiferous patches present; grades into subjacent bed.....	4.2	259.8		
<i>Freezeout tongue of Chugwater</i>				
Red shale.....	24.3	255.6		
Gypsum.....	2	231.3		
Red shale.....	13	229.3		
Gypsum.....	5	216.3		
Red shale.....	52.8	211.3		
Gypsum grading downward into 6 inches of porous gray limestone.....	7.3	158.5		
Red shale.....	2.7	151.2		
FORELLE LIMESTONE				
Finely laminated, crinkly gypsum.....	7.5	148.5		
Finely laminated, dense, purple limestone.....	3	141		
Dense, crinkly, gray limestone with a few angular chert masses of small size. Caps mesa known as Gypsum Butte.....	5	138		
SATANKA SHALE				
Red sandy shale.....	72	133		
Gypsum with a few thin beds of red shale, one of which contains numerous masses of aragonite which are pseudomorphs after banksite*.....	53	51		
Pinkish shaly limestone, mostly unfossiliferous but with a-foot bed of fossil coquina in center; brecciated in places.....	5	8		
Olive-colored flaky shale.....	3	3		
CASPER FORMATION: not measured.				
TOTAL.....		261.8		

* N. H. Darton and C. E. Siebenthal, *U. S. Geol. Survey Bull.* 364, p. 24.

fauna collected by W. C. Knight and identified by G. H. Girty has erroneously been reported as occurring in the Forelle. The following species have been collected by the writer; those previously listed by Darton and Siebenthal⁵⁹ as from the Forelle are marked by asterisks.

<i>Allorisma capax</i> Newberry.....	c
* <i>Deltopecten</i> cf. <i>D. coreyanus</i> (White).....	c
* <i>Deltopecten manzanicus</i>	c
* <i>Myalina perattenuata</i> Meek and Hayden.....	c
<i>Myalina</i> cf. <i>M. aviculoides</i> Meek and Hayden.....	r
<i>Myalina</i> cf. <i>M. permiana</i> Swallow.....	c
* <i>Plagioglypta canna</i> (White).....	c
* <i>Pleurophorus</i> aff. <i>P. taffi</i> Girty.....	c

⁵⁹ N. H. Darton and C. E. Siebenthal, *op. cit.*; Willis T. Lee, *op. cit.*; C. C. Branson, *Univ. Missouri Studies*, Vol. 5, No. 2 (1930).

* <i>Schizodus compressus</i> Beede.....	c
* <i>Schizodus meekanus</i> Girty.....	c
<i>Bellerophon crassus</i> Meek and Worthen.....	c
<i>Coelogasteroceras</i> cf. <i>C. mexicanum</i> (Girty).....	r

In addition, Darton and Siebenthal listed "*Allorisma terminale*, *Solenomya* sp. and *Orthonema?* sp." which the writer has not identified.

This fauna has been cited by C. C. Branson⁶⁰ as bearing affinities to the fauna of the top limestone of the Phosphoria of the Wind River Mountains. The fossils, however, occur far below the Forelle, and the fauna can not be contemporaneous with that of the top limestone of the Phosphoria.

PALEOGEOGRAPHY AND LITHOGENESIS

The best discussion of the paleogeography of Phosphoria time has been given by Mansfield.⁶¹ He points out, however, that large gaps exist in the knowledge regarding the facts on which such a discussion is based. Much more detailed information is necessary before a true reconstruction can be formulated of the conditions under which the rocks of Phosphoria time and of Dinwoody time were deposited. Of prime importance is the establishment of the definite ages of the formations. With this in mind, the writer ventures to add to the existing knowledge the information gained through the study of the relatively small area embraced by this paper.

PHOSPHORIA TIME

Paleogeography.—The area covered by the Phosphoria sea on Mansfield's paleogeographic map⁶² must be extended eastward. During portions of Phosphoria time the sea entirely covered central and southeastern Wyoming. At present it is not known how much farther eastward the sea extended.

The locations of positive areas which supplied land-derived material during Phosphoria time are not definitely known. Their character, however, was apparently quite different from that of the land masses which supplied material for the Pennsylvanian sediments of central and southeastern Wyoming, for the Permian land masses did not furnish such coarse clastic material as those of the Pennsylvanian.

A land mass in north-central Colorado, which undoubtedly furnished sediments during Pennsylvanian time, was overlapped and buried by sediments of Phosphoria age. In North Park, Colorado

⁶⁰ *Op. cit.*, p. 21.

⁶¹ G. R. Mansfield, "Geography, Geology and Mineral Resources of Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper* 152 (1927), pp. 184-88.

⁶² *Ibid.*, Fig. 22, p. 185.

(Fig. 1), the pre-Cambrian granite is overlain by about 100 feet of alternating red shales and limestones probably of Phosphoria age. Limestones comprise 35 feet of the total thickness.⁶³ The small percentage of land-derived material in this section compared with sections in central Wyoming, and the comparative thinness, suggest that the terrigenous material present in central Wyoming did not come directly from the south. It may be said, however, that insufficient evidence is at hand to indicate the importance of Colorado land masses in contributing to the Phosphoria sediments.

The increase in the amount of clastic material in the sediments of Phosphoria age from west to east across Wyoming seems to indicate that some of the material came from east of Wyoming. Regarding the distribution of the Permian seas, P. B. King⁶⁴ says:

During Permian time an embayment from the Gulf of Mexico extended inland through Mexico into western Texas, where it divided into two branches, one of which reached northeast into the mid-continent region beyond Nebraska and the other penetrated the Cordilleran region of New Mexico, Arizona and Utah.

Inasmuch as the Phosphoria sea was a part of the Cordilleran invasion, the region lying east of Wyoming, between these two embayments, seems to be a logical source of supply for some of the terrigenous material of the sediments of Phosphoria age in southeastern Wyoming, although the source does not seem adequate. Possibly, some of the material was distributed northward from the east side of the Paleo-Rockies in central Colorado.

Sedimentary environments.—If residual red soils were being produced by weathering of rocks in the positive areas, it is possible that such soil would be transported and deposited along the margin of the Phosphoria sea as red material. Certain facts lead the writer to believe that most of the red shale tongues were deposited in a specialized marine environment. Individual beds of red shale show slight variation in thickness or in texture over wide areas. Mud cracks or rain-drop impressions have never been noted in the red shales. These red beds lack the lithologic features characteristic of the Fountain formation (Pennsylvanian) and the Jelm formation (Upper Triassic). Both are red beds of unquestionable continental origin, characterized by lenticularity of beds, rapid changes in texture within short distances, channeling and cross-lamination. Poorly preserved marine fossils have been found in a thin limy red bed in the Satanka in the Laramie Basin, and over most of the region thin beds of red shale are inter-

⁶³ S. H. Knight, personal communication.

⁶⁴ P. B. King, "The Geology of the Glass Mountains," Pt. 1, *Univ. Texas Bull.* 3038 (1930), p. 89.

bedded with limestones or sandstones of undoubted marine origin. Mansfield⁶⁵ has shown that the beds of chert within the Phosphoria are chemically precipitated marine deposits. Just below the Ervay tongue in the Rattlesnake Hills are thin beds of laminated chert intercalated with beds of red shale. This suggests that the conditions under which the chert was deposited were not markedly different from the conditions under which the red shale was deposited. The thick gypsum beds in the red shales indicate some relationship to a marine environment. The absence of fossils in the red beds has no bearing on their origin; both continental and marine beds are frequently found to be unfossiliferous. However, if the unfossiliferous nature of the red beds of Phosphoria age be interpreted as the result of the absence of organisms in a specialized marine environment, the red material could have been deposited without the reduction of its ferric iron and with the retention of its original color.

Western Wyoming, then, was occupied during Phosphoria time by a sea in which the typical facies of the formation was deposited. At the same time, a marginal portion of the sea covered southeastern Wyoming. Here were deposited red sediments which intertongued with the typical facies of the Phosphoria. It is not known whether this relationship was brought about by oscillatory movements of the sea or whether it was the result of intermittent cessation of uplift in the land masses which supplied the red clastic material. Both would allow the clear water zone favorable to the deposition of limestone to move eastward. It seems best, however, to think of the red beds as a marginal deposit built out westward in an oscillatory sea. During the time of deposition of any limestone tongue, the sea would be most widespread and the red-bed marginal facies would migrate eastward. With regression of the sea the red-bed facies would move back toward the west. The transgressions were rapid and probably of short duration, for some of the limestone tongues, although thin, cover hundreds of square miles. That the rate of sedimentation was not markedly slower during times of limestone deposition is indicated by the fact that the thickness of the typical facies of the Phosphoria is not much less than the thickness of the formation where it is split by tongues of red shale. The lack of terrigenous material in the limestone tongues indicates, however, that any particular locality was separated from the source of supply of the red sediments by a greater extent of water during limestone deposition than during red shale deposition. It is believed that the clastic material of the Sybille tongue had a different source from that of the red shales. This may be accounted

⁶⁵ *Op. cit.*, pp. 367-72.

for by the fact that the Phosphoria sea, as shown by Mansfield, was a more or less enclosed body of water.

The limestones in the red-bed facies are diverse in origin. Many of them are due to the accumulation of calcareous organic material. Only a few of these beds yield recognizable fossils because of the broken condition of the shells. The extremely fine-grained, finely laminated limestones may be the result of deposition of chemically precipitated lime. It is apparent that they were deposited in water which was not agitated enough to obliterate fine lamination. The sedimentary environment in which these limestones were deposited is in contrast with that of the breccia beds, whose origin has been attributed to contemporaneous erosion in highly agitated water.

The mode of origin of the gypsum beds is not well understood. It is believed that many of the thinner ones are replaced limestones; most of the thicker ones are undoubtedly chemical precipitates.

In interpreting the origin of the chert in the Phosphoria formation, Mansfield was influenced by Lee's belief that the Phosphoria was older than the red-bed "Embar" and that the two were separated by an unconformity.⁶⁶ Hence, Mansfield believed that a low peneplane cut on the Tensleep sandstone formed the land surface east of the Phosphoria sea,⁶⁷ which he thought was confined to western Wyoming. He pointed out that such conditions have been postulated by W. A. Tarr as being conducive to the deposition of chemically precipitated chert beds, and he used Tarr's theory in explaining the origin of the Phosphoria chert.

The paleogeography postulated by Mansfield must be revised, however, for the sea was more widespread and instead of being bordered by peneplaned sandstone was adjacent to land which supplied clastic red sediments. Furthermore, by the time that chert deposition became prominent in the Phosphoria, the peneplaned Tensleep sandstone of central Wyoming, which was considered as the probable source of the silica in the cherts, had long been buried by red beds.

DINWOODY TIME

The same land masses which supplied the red sediments of Phosphoria age continued to produce similar material which was carried over southeastern and central Wyoming during Dinwoody time. However, the red shales, instead of interfingering toward the west with limestones and chert as during Phosphoria time, graded into

⁶⁶ G. R. Mansfield, *op. cit.*, p. 373.

⁶⁷ *Ibid.*, p. 372.

clastic shales and limy sandstones. This means, perhaps, that a positive area on the western border of the Dinwoody sea began to function and to give rise to the land-derived material in the typical Dinwoody, or that the Dinwoody is a seaward facies of the red shales which was deposited under reducing conditions, resulting in the loss of the red color of the sediments. A maximum advance of the sea during the time of deposition of the Little Medicine tongue was followed by a retreat throughout the remainder of Dinwoody time, and caused the red-bed facies to migrate westward with its base rising in the column (Fig. 3).

BOUNDARY BETWEEN PALEOZOIC AND MESOZOIC

The effects of the almost world-wide crustal unrest during the interval between the Paleozoic and the Mesozoic eras are conspicuously absent in central or southeastern Wyoming. If the age of the Phosphoria is Middle Permian and that of the Dinwoody is Lower Triassic, there must be, between the formations, an unconformity which represents an interval of non-deposition of considerable duration. If such a break is present it is not conspicuous. The areal extent of the red-bed and normal marine environments during Phosphoria time was almost identical with the areal extent of similar environments during Dinwoody time, indicating that no marked changes in the crustal configuration took place between the times of deposition of the two formations. There is no measurable angular discordance between the Phosphoria and the Dinwoody to indicate diastrophism between Phosphoria time and Dinwoody time.

Even though the Dinwoody should be found to be Permian, or be found to represent the interval between the Permian and the Triassic, there is still no well defined break between Paleozoic and Mesozoic rocks. In southeastern Wyoming sedimentation was apparently continuous from the Forelle portion of Phosphoria time, through Dinwoody time, until the close of Chugwater time. However, between Chugwater time and Upper Triassic (Jelm) time the region was gently warped and the strata beveled by erosion, so that the younger members of the Chugwater progressively disappear from north to south.

CLIMATE

The evidence bearing on the climate of Phosphoria time and Dinwoody time is meager. The production of residual soils indicates a source in which oxidation dominated over reduction. The presence of locally abundant gypsum suggests high evaporation with a relatively small inflow of fresh water, such as would characterize a warm, arid

climate. The Phosphoria sea, during times other than those of phosphate deposition, swarmed with organisms which are similar to those which inhabited the warm Pennsylvanian seas. Mansfield,⁶⁸ however, believes that the phosphate beds in the Phosphoria are a reflection of a cool climate.

DIFFICULTIES IN PALEONTOLOGIC CORRELATION

Most of the organisms which lived in the portion of the Phosphoria sea which is now occupied by the Wind River Mountains were markedly different from the organisms which are now found farther east and south as fossils in limestones and sandstones intercalated in red beds. Most of the faunules of the Phosphoria of the Wind River Mountains consist principally of brachiopods and bryozoans, a feature which contrasts strongly with the molluscan character of the faunules of the calcerous facies in the intertongued phase. The differences in the two types of faunules indicate strongly that they lived in distinctly different environments. There were, however, certain genera or species living during Phosphoria time which were not sufficiently specialized to be confined to one set of environmental conditions. The genus *Myalina*, for example, is found in the Phosphoria of both the Wind River Mountains and the intertongued phase, but certain species of the genus are confined to the former and others to the latter. *Plagioglypta canna* seems to have been able to exist in equal abundance in both environments.

Between the two areas providing the two distinct types of environment there was undoubtedly a zone of environmental gradation in which certain genera or species found in one type of faunule could exist and intermingle with certain genera and species found in the other type. The faunule of the Ervay tongue in the Rattlesnake Hills furnishes a good example of this environmental gradation and consequent faunal intermingling. The organisms of the molluscan type of faunule in the intertongued phase are here represented by *Schizodus*, *Myalina*, *Pleurophorus* and *Pinna*, and the organisms of the Phosphoria of the Wind River Mountains by *Composita*, *Derbyia*, *Punctospirifer*, *Euphemus*, and numerous bryozoans.

The writer believes that the erroneous paleontologic correlation of beds in the intertongued phase with certain horizons in the Phosphoria and Dinwoody of the Wind River Mountains has resulted from relying too strongly on general faunal similarity and on the presence of species which are found in both areas. General faunal similarity and common species are not always reliable criteria for correlating beds

⁶⁸ *Op. cit.*, p. 366.

which occur in different sedimentary facies. Most of the fossils in the intertongued phase of the Phosphoria are long-ranging species. Similarities in faunas of markedly different age may result from these long-ranging species appearing at one locality under certain environmental conditions and appearing much later at another locality upon the initiation there of a suitable environment.

SUMMARY

Marine limestone and sandstone tongues extend southeastward from the Phosphoria and the Dinwoody formations of the Wind River and the Owl Creek mountains, intertonguing with the red shales in the base of the Chugwater formation in central and southeastern Wyoming. The nature of the intertonguing has been demonstrated through lithologic and faunal correlation of sections. Significant stratigraphic units have been defined and named.

GEOLOGICAL NOTES

FREDERICKSBURG-WASHITA (EDWARDS-GEORGETOWN) CONTACT IN EDWARDS PLATEAU REGION OF TEXAS

A series of limestones varying in thickness from 370 to 560 feet lies between the Comanche Peak formation and the Del Rio clay in Kerr, Real, Edwards, Kimble, and Sutton counties of the Edwards Plateau region of Texas. The lower portion of the section is the Edwards limestone, which marks the top of the Fredericksburg division of the Lower Cretaceous (Comanche) in this area. The limestones lying beneath the Del Rio clay belong to the Georgetown of the lower Washita division.

Although the ages of the extremes of this series are well known, the actual contact of rocks of the two divisions has not been defined. In fact, the definition of the Edwards limestone has never been clear. In the popular usage of the term "Edwards," it is loosely applied to the Comanche Peak, Edwards proper, Georgetown, or the whole series. While discussing the confusion that has arisen concerning the upper limits of the Edwards on correlations by rudistid levels, Adkins¹ says:

In addition, the Edwards formation suffers through vagueness in the specification of its type locality. It was formerly called Barton Creek limestone, from the locality near Austin, and this name was in 1901 changed to Edwards. The Edwards Plateau, even in Edwards County, has various beds at its surface, some of them High Washita (Del Rio, at least). Furthermore, Hill² states that the top of the Fredericksburg Division was originally located on the basis of ammonite ranges (i.e., essentially at the top of *Oxytropidoceras*) but was later changed to a rudistid basis to conform to the well known rudistid level at Austin. When then rudistids were found at higher levels, the top of the Edwards was left undefined paleontologically.

Considering the broad outcrop over the Edwards Plateau as a whole, it is almost impossible to place a dependable line of demarcation between the Edwards and Georgetown on lithologic grounds alone. Attempts have been made to distinguish the Edwards by its

¹ W. S. Adkins, "The Geology and Mineral Resources of the Fort Stockton Quadrangle," *Univ. of Texas Bull.* 2738 (1927), p. 60.

² R. T. Hill, *U. S. Geol. Survey Twenty-First Ann. Rept.*, Pt. 7 (1901), pp. 118-19.

chert content, but there are localities where the chert seems to range well into the Georgetown. In certain areas the Georgetown is said to be softer and to produce a characteristic topography of low-lying



FIG. 1.—Soft limestone with *Gryphaea*, base of Washita (Georgetown). Western Kerr County, Texas.

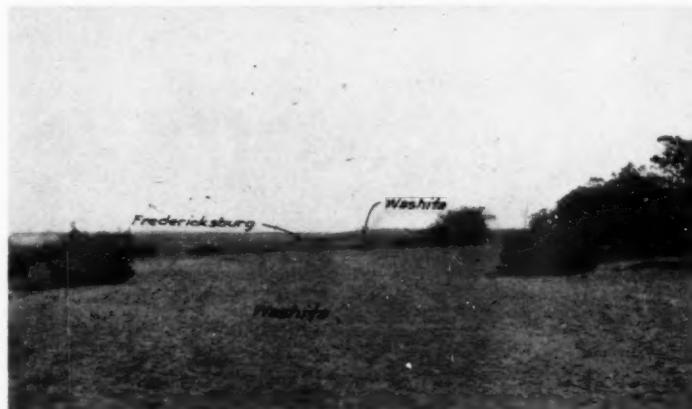


FIG. 2.—Topographic bench formed by weathering of Washita (Georgetown) *Gryphaea* bed.

hills and gentle slopes, but there are equally as many localities where the Edwards is composed of soft limestones and forms a similar topography. Faunal zones of *Caprinidae* are characteristic of the upper

limestones, but they are associated with *Requienia*, *Toucassia*, and *Ostrea*, which are found throughout the series.

For the field geologist, the only definite feature which may separate the series into distinguishable lower and upper portions of Fredericksburg and Washita age, respectively, is a horizon of *Gryphaea*



FIG. 3.—Contact of fossiliferous Washita (Georgetown) limestone containing *Gryphaea* and underlying Fredericksburg (Edwards) limestone. Photograph shows difference in character of the two deposits, southeastern Sutton County, Texas.

(Fig. 1), the base of which is from 130 to 220 feet below the Del Rio clay. The variation in thickness is due to an unconformity at the top of the Georgetown.

In the area under consideration, the soft limestones containing the *Gryphaea* weather to a broad topographic bench (Fig. 2) with a rocky, chert-bearing slope immediately beneath. The base of the *Gryphaea* bed is quite definite (Figs. 3 and 4), but in some places

the fossils range upward a distance of 40 to 50 feet where another well developed *Gryphaea* bed appears. However, the latter is not so persistent. Specimens from the lower part of this zone are lower Washita in age in the opinion of T. W. Stanton of the United States Geological Survey, who says:

I have examined your small collection of *Gryphaea* from the western part of Kerr County, Texas, and find that most of them apparently belong to a form which I have been calling *Gryphaea corrugata* variety with radial sculpture. In my experience in western Texas this form has been found low in the



FIG. 4.—Contact of soft Washita (Georgetown) limestone containing *Gryphaea* with harder non-fossiliferous Fredericksburg (Edwards) limestone, southeastern Sutton County, Texas.

Washita group in rocks which I believe to be of the age of the lower part of the Duck Creek formation. It is always desirable and usually possible to check this correlation by means of associated ammonites and other kinds of fossils which are safer guides in matters of close correlation than the extremely variable Comanche species of *Gryphaea* are.

There are no specimens of *G. navia* in your collection but there is one which may belong to a broad variety of *G. corrugata* such as *tucumcarii*.

As far as is known, no ammonites have been found associated with the *Gryphaea* in Kerr, Real, Edwards, or Kimble counties. However, in Sutton County, particularly the western part, ammonites are occasionally found in the *Gryphaea* zone. In northeast Sutton County one specimen, which was identified as *Desmoceras* by W. S. Adkins of the Bureau of Economic Geology, University of Texas, was found about 20 feet above the *Gryphaea* bed in eastern Sutton County,

northwest of Fort Terrett, by V. A. Brill of the Humble Oil & Refining Company. Other fragments of this fossil were found approximately 50 feet above, and sporadic occurrences of the form *Oxytropidoceras* were noted about 20 feet below the *Gryphaea*. The ammonite genus *Desmoceras* is accepted as a definite Duck Creek, or basal Washita, marker, while *Oxytropidoceras* is distinctly a Fredericksburg fossil.

In the extreme southeastern part of Crockett County, practically on the Crockett-Sutton County line and approximately eight miles north of the county corner, fragments of the ammonite *Pervinquieria*³

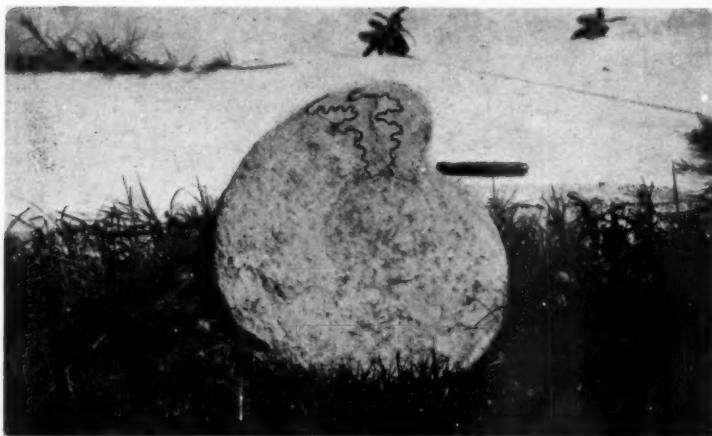


FIG. 5.—*Desmoceras ? brazoense* (Shumard) found associated with *Gryphaea* approximately 25 feet above base of fossil zone. This ammonite, together with species of *Pervinquieria*, found at same locality, is usually found in beds equivalent in age to Duck Creek of lower Washita. Found in limestone quarry 0.4 mile northeast of Sonora, Sutton County, Texas.

were found 25 feet above the base of the *Gryphaea* zone. *Pervinquieria trinodosa* is a Washita fossil, which is usually found in beds equivalent in age to the Duck Creek. Beneath the soft marly limestones bearing the *Gryphaea* and ammonite, the beds are of an entirely different character. The Edwards limestones below are hard and contain a great deal of chert; the fossils they contain are fragments of *Ostrea* and *Raquienia*.

³ W. S. Adkins, *Univ. Texas Bull.*, 3232, 1932 (1933), p. 364. These Washita ammonites should be referred to *Mortoniceras* Meek 1876 (Genotype *Ammonites vespertinus* Morton).

L. F. Spath, *Monograph on the Ammonites of the Gault*, Pt. IX, p. 379. *Pervinquieria* is a synonym for *Mortoniceras*.

In the floor of a quarry just northeast of the town limits of Sonora, central Sutton County, two ammonites were found associated with *Gryphaea*. These fossils have been identified as *Desmoceras brazoense?* Shumard (Fig. 5), and *Pervinquieria* sp. of the Duck Creek fauna by T. W. Stanton. The ammonites were found approximately 25 feet above the base of the *Gryphaea* zone.

Adkins and Winton⁴ found *Gryphaea corrugata* Say ranging from the Kiamitia of North Texas into the Duck Creek, and both formations were considered lower Washita. In a later work, *G. corrugata* H. and V. is listed both as a Kiamichi (note difference in spelling) and a Duck Creek fossil by Adkins⁵ who places the Kiamichi together with some "post-Kiamichi clays" at the top of the Fredericksburg in the Fort Stockton Quadrangle.

Thus it may be established with a fair degree of assurance that the Fredericksburg-Washita contact lies in the vicinity of the *Gryphaea* bed. It is possible that this fossiliferous zone represents both the Kiamichi and the Duck Creek of the lower Washita, but no characteristic Kiamichi fossils have been identified. In view of the widespread occurrence of *G. corrugata* in the Duck Creek, the occurrence of Duck Creek ammonites with the *Gryphaea*, and the fact that there is a distinct faunal and lithologic break at the base of the zone (Fig. 3), whereas the upper limits may be gradational, the writer believes the more logical position for the Fredericksburg-Washita contact is at the base of the *Gryphaea* bed. Under this interpretation, the soft to marly limestones of the *Gryphaea* horizon may in part be equivalent to the Duck Creek formation of North Texas. They may also be equivalent to the Georgetown limestone of the Fault zone which contains *Gryphaea*. The underlying chert beds may be correlated with those encountered at the top of the Edwards limestone in Salt Flat⁶ and other Edwards limestone oil fields.

It is interesting to know that the Washita may be as much as 245 feet thick in this area. This thickness may include 220 feet of Georgetown limestone (or its stratigraphic equivalents), 8-20 feet of Del Rio clay, and 5-25 feet of Buda limestone which is found on top of the high divides. Toward the south and southwest, the *Gryphaea*

⁴ W. S. Adkins and W. M. Winton, "Paleontological Correlation of the Fredericksburg and Washita Formations in North Texas," *Univ. of Texas Bull.* 1945 (1919), pp. 62-69.

⁵ W. S. Adkins, "The Geology and Mineral Resources of the Fort Stockton Quadrangle," *Univ. of Texas Bull.* 2738 (1927), p. 60.

⁶ L. F. McCollum, C. J. Cunningham, and S. O. Burford, "Salt Flat Oil Field, Caldwell County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 11 (November, 1930), p. 1408.

horizon changes facies to indurated rudistid-bearing limestones which render the Edwards-Georgetown contact indistinguishable. The combined series is known as the Devils River limestone from its occurrence along the Devils River in Val Verde County, Texas. In the Fort Stockton Quadrangle, Adkins⁷ finds the Washita to be 245 feet thick. In the Fault zone, 140 miles farther east, there is approximately 170 feet of Washita but the members are of nearly equal thickness, the Georgetown being 60 feet, the Del Rio 50 feet, and the Buda 60 feet.⁸

The following is a generalized section in Edwards County from Paint Creek on the north to the vicinity of Rock Springs on the south. The increases in thickness are from north to south and are determined by using the *Gryphaea* horizon as the base of the Georgetown. South of the major drainage divide on which the town of Rock Springs is situated, the *Gryphaea* bed can not be recognized. For this reason, estimates of the thickness of Georgetown in southern Edwards County are qualified by the limit of accuracy in correlating upper beds across the divide.

	Thickness in Feet	
<i>Buda limestone</i>	Marl similar to Del Rio which is capped by hard white-to-cream-colored limestone; found on top of highest divides; supports dense thickets of small oak trees which contrast markedly with open grassy lanes of Del Rio clays; contains corals, <i>Holectypus</i> ? sp., <i>Spondylus texanus</i> Whitney, <i>Homomyia</i> ? sp., <i>Pecten</i> sp., <i>Pholadomya</i> , sp., <i>Budaiceras</i> , sp., <i>Exogyra</i> , <i>Endolaster</i> ? sp., <i>Heimaster</i> , sp., <i>Tylostoma</i> , sp., <i>Lima</i> , sp., <i>Protocardia</i> , sp., <i>Cyprinaria</i> , sp., <i>Pleurotomaria</i> , sp., <i>Nautilus</i> , sp. ⁹	5-25
<i>Del Rio clay</i>	Soft marl weathering deep yellow; forms low hummocks and broad topographic benches on top of Edwards Plateau proper; contains <i>Exogyra arietina</i>	10
<i>Georgetown limestone</i>	Alternating beds of hard and soft limestone; lower 100 feet on headwaters of Nueces River contains massive chert beds; alternation of hard and soft beds gives characteristic topographic benches and mesas of uplands; supports vegetation of cedar, live oak, scrub oak, and mesquite; contains <i>Caprinidae</i> , <i>Requienia</i> , <i>Toucasia</i> , <i>Ostrea</i> , <i>Gryphaea</i> , <i>Desmoceras brazoense</i> (Shumard), <i>Pervinquieria</i> , sp., gastropods	150-220
<i>Edwards limestone</i>	Hard limestone with nodular chert beds, fossiliferous marls, thin-bedded porous limestone with "honeycomb" weathering; hard limestones form steep rock slopes and cliffs but marl beds weather to form gentler slopes; basal portion is water horizon (base of Edwards arbitrarily placed at base of thin-bedded chert-bearing limestones); supports dense cedar "breaks"; contains <i>Gryphaea marcoui</i> , <i>Requienia</i> , <i>Eoradiolites</i> , <i>Oxytropidoceras</i> , gastropods, echinoids	285-340

⁷ W. S. Adkins, *op. cit.*, p. 30.

⁸ L. F. McCollum, C. J. Cunningham, and S. O. Burford, *op. cit.*, pp. 1407-08.

⁹ Identified by T. W. Stanton, U. S. Geol. Survey. Where the ammonite, *Budaiceras* is not present the bed is classified as "probably" or "possibly" Buda.

<i>Comanche Peak</i>	Marly limestone softer than overlying Edwards limestone; forms cliffs along water courses; basal 4 feet on Paint Creek is gray shale in part equivalent to Walnut clay facies farther north and to basal limestone of Comanche Peak farther south; supports dense growth of Spanish oak; contains gastropods, <i>Gryphaea marcoui</i> , and abundance of <i>Exogyra texana</i> in gray shale and basal limestone portions	
<i>Glen Rose</i>	Blue-green shale, white chalky limestone, marls alternating with hard fossiliferous limestones	30-40 450-500

W.M. H. CURRY, JR.

SHELL PETROLEUM CORPORATION
 HOUSTON, TEXAS
 October, 1934

PORTABLE SEDIMENTARY LABORATORY

Most geologists must have had occasion at some time or other to regret the fact that sedimentary analysis of rock samples, collected during expeditionary surveys, must necessarily lag far behind the field work. Frequently, however, preliminary microscopic examination of selected specimens may reveal outstanding features of immediate value in the prosecution of the survey. Moreover, detailed field work may be facilitated in areas where something is already known of the microscopic characters of the rocks, if means are available for recognition of those characters on the spot.

Many geologists have doubtless improvised equipment to bridge the gap between the field and the laboratory; crude methods of panning for separation of heavy minerals, micro-fossils, et cetera have long been used, while apparatus for preparation of rock sections is often included in the field kit.

The writer's portable sedimentary laboratory is an attempt at refinement and is described in the hope that criticism may lead to the development of an ideal outfit for the purpose.

PORTABLE EQUIPMENT FOR PREPARATION OF THIN ROCK SECTIONS,
 MINERAL RESIDUES, AND MICRO-FOSSIL CONCENTRATES.

The apparatus is contained in a strong, mortise-jointed box of 1.75-centimeter wood, measuring over all $62 \times 21 \times 35$ cms., the size and shape being suitable for transport by pack animal or porter or on the running-board of a car. The box is provided with a good lock, strong rope handles at each end, and metal loops for binding cords.

The lid, when fully opened, rests on two props fitted into notches on the lid which serves, therefore, as a small working bench (Fig. 3).

A cloth wind-screen with wire supports provides shelter as illustrated; when not in use it is rolled up and bound to the side of the box.

Two or more brass-lined sockets are drilled into the upper edge of the front side of the box on either side of the lock; these are to hold iron rods which serve as the uprights of funnel stands.¹

Internally the box is subdivided into four parts.

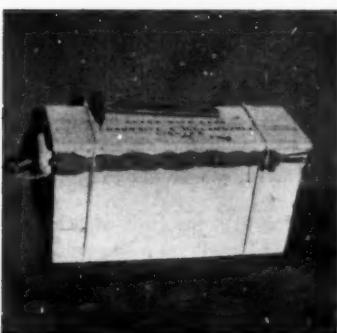


FIG. 1

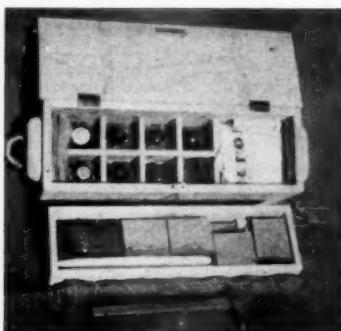


FIG. 2



FIG. 3



FIG. 4

FIGS. 1-4.—Portable sedimentary laboratory

1. A narrow compartment ($2.5 \times 17.5 \times 23.5$ cms.) for steel grinding plates and other metal parts (Fig. 2, left)
2. Eight pigeon-holes (each $8 \times 8 \times 23.5$ cms.) for bottles containing chemicals (Fig. 2, center)
3. A large compartment ($20 \times 17.5 \times 23.5$ cms.) for miscellaneous apparatus (Fig. 2, right)
4. A shallow tray (external dimensions $58 \times 17 \times 7$ cms.) fitting into the box above the other compartments and containing a portable microscope and other items which it is desirable to keep apart from the chemical apparatus (Fig. 2, below)

When traveling all contents are securely packed in with cotton waste and in actual experience breakages were very few.

¹ The photographs show a funnel stand occupying a similar position but improvised from a retort-stand clamp.

The outfit contains the following items.

A. General purposes

- 1 microscope, petrological, portable, in case
- 1 bulls-eye condenser
- 1 lamp, heating, glass, for methylated spirit (200 ccs.)
- 0.5 liter methylated spirits, in bottle
- 1 tripod, iron, collapsible
- 1 wire gauze, 13×13 cms.
- 5 dishes, porcelain, assorted, 18-6.5 cms. diameter
- 2 basins, aluminium, 15 and 13 cms. diameter
- 2 funnels, glass, 10.25 cms. diameter
- 4 pinch-cocks
- 1-meter rubber tubing, 0.64 cm. diameter
- 4 glass rods, 15 cms.
- 2 retort-stand rings, 10.25 cms. diameter, for funnel stands
- 2 iron rods, 20.5 cms., for funnel stands
- 1 spatula
- 1 hammer, trimming, 80 grms.
- 1 knife, folding
- 2 glass cloths
- 3 gross labels, gummed, 2.25×2.25 cms.
- 2 pencils, 2H and 4H.
- 30 gms. gum arabic, solid
- 2 boxes filter paper, No. 2, 11 cms. diameter.
- 4 watch glasses, 11.5 cms. diameter

B. Preparation of thin rock sections et cetera

- 2 plates, steel, grinding, 16.5 cms. diameter \times 0.6 cms.
- 1 kilo. carborundum powder, No. 120
- $\frac{1}{2}$ kilo. emery flour
- 1 snakestone hone, $5 \times 2.5 \times 0.6$ cm.
- 1.5 gross slide glasses, 7.68×2.56 cms.
- 1.5 gross cover slips, 2.56×2.24 cms.
- 0.5 kilo. Canada balsam, in bottle
- 1 pr. forceps
- 1 plate, copper, heating, $15.5 \times 7.7 \times 0.32$ cms.
- $\frac{1}{2}$ liter, methylated spirits, in bottle, for cleaning slides
- 1 tooth-brush for cleaning slides

C. Preparation of micro-fossil and mineral concentrates

- 1 kilo. caustic soda, solid, in bottle
- 0.5 liter hydrochloric acid, conc., comm., in bottle
- 0.5 liter bromoform, in bottle
- 0.5 liter benzol or petroleum ether, in bottle with bung and glass tubing for conversion to wash-bottle
- 1 bottle (0.5 liter cap.) for bromoform washings
- 25 gms. cedar-wood oil, in bottle, with glass stopper and rod
- 1 set sieves, nested, max. diameter 14 cms., mesh 40, 80, 200
- 1 picking tray, enamelled black with white grid ruling, 11.5×7.0 cms.
- 4 brushes, camel-hair and red sable assorted
- 1 pr. forceps
- 60 cell mounts with cover slips
- 24 vials, glass, round-bottomed, 2.56×3.2 cms, with corks
- Paper cylinders stopped at each end with cotton-wool, made as required for storage of concentrates

The foregoing list covers minimum requirements, but work is considerably facilitated by the following additions which were carried separately, but which might be accommodated in a re-designed and enlarged case.

- 1 pestle and mortar, metal
- 1 vapor stove, small, portable, for gasoline or kerosene
- 1 water-bag, canvas, fitted at top with filler-cap and rope handle and at bottom with a stopcock; and filter to which is attached a length of rubber tubing with a pinch-cock; when suspended from a tent-pole or other support above the working bench, this device gives a convenient regulated supply of running water

While good results have been obtained with the portable microscope included in the minimum equipment, the advantages of using a more elaborate instrument with proper lighting arrangements will generally outweigh transport considerations.

SCOPE AND METHODS OF WORK

The technique of sedimentary analysis is too well known² to require detailed description in the present note. It is sufficient to state that the apparatus described has been used successfully for making the following preparations.

1. Thin sections of all types of rocks, from the hardest to the softest; special sections of larger *Foraminifera* et cetera
2. Graded micro-fossil concentrates
3. Heavy and light mineral residues

Mechanical analyses were not attempted, though a few additions to the equipment would bring them within the range of possibility. However it is doubtful whether such work would yield useful results unless carried out on a large scale.

The amount of work accomplished with the portable laboratory naturally varies greatly according to circumstances. In ordinary conditions, however, using the minimum equipment described, it is possible to make complete series of preparations from five to ten samples per day. With duplication of certain apparatus (heating stoves et cetera), the daily output may be increased, while a larger number of samples may be handled if, as is usually the case, it is not necessary to make the full range of preparations from each specimen.

For operation of the portable laboratory the writer engaged and trained an intelligent youth at a rate of less than a dollar a day.

With an assistant working in camp, or at any convenient rendezvous (since the outfit is designed for use in the open air, given reasonable weather conditions), important rock samples collected one day, are ready prepared for microscopic examination by the evening of the next. Field geologists will appreciate the value of such an arrangement which readily becomes a routine.

The question of replenishing chemicals, replacing breakages et cetera, will at once occur to geologists familiar with the difficulties

² See H. B. Milner, *Sedimentary Petrography*; J. A. Cushman, *Foraminifera, Their Classification and Economic Use*; et al.

of expeditionary work in remote areas. Substitution of metal for glass apparatus would solve part of the difficulty at increased cost. As regards chemicals, consumption is normally high in relation to the quantities carried only in the case of hydrochloric acid and methylated spirits.

Acid should be used for cleaning only the most resistant cemented rocks since caustic soda is efficacious and indeed preferable for digestion of most soft sediments. Reserves of solid caustic soda are easily carried while the amount allowed for minimum requirements is sufficient for 170-200 alkali digests even without re-use of solution.

Methylated spirit is not indispensable either as a solvent for Canada balsam in slide making, or as a fuel.

Slide-making materials are sufficient for 100-200 thin sections, depending on the nature of the rocks to be cut.

The consumption of bromoform and benzol under field conditions was never fully tested, but a minimum estimate would allow for some scores of separations.

In the matter of improvisations it is difficult to foresee all possibilities, but many economies and substitutions of method or material will occur to the experienced operator and enable him to carry on even in adverse circumstances.

F. R. S. HENSON

LONDON, ENGLAND
September 30, 1934

DISCUSSION

ORIGIN OF BARTLESVILLE SHOESTRING SANDS, GREENWOOD AND BUTLER COUNTIES, KANSAS

Mr. Bass has done a very excellent and careful piece of work in this article, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," in the October *Bulletin*, pp. 1313-45, and should be complimented for it. His belief in the offshore-bar theory is quite reasonable, well advanced, and effectively illustrated. I am not convinced that his theory is incorrect, in fact I have twice been a believer in it but also I have twice believed in the stream-channel-filling theory, and therefore, think it advisable to point out that some of Mr. Bass' facts are debatable and can, with added information, be used to support either belief. Possibly some of the data are more favorable to the stream-channel theory.

To begin with, I would postulate a gently sloping land mass recently raised above the sea, across which drainage would follow the quickest way to the ocean. Since the surface was quite flat the streams should be straight. The Warrensburg and the Moberly channel deposits of Missouri mentioned by Mr. Bass are exceptionally straight. A meandering stream is an old-age stream. Thus the straightness of the sand bodies can be explained by the stream theory as well as by the bar theory.

These sand bodies have many thin black carbonaceous partings: in places, 10-15 in 1 inch of thickness; in many places, covered with a scattering of white mica. Some of these carbonaceous partings range from $\frac{1}{8}$ to $\frac{1}{2}$ inch in thickness and have a fracture and luster exactly like that of coal. Such partings could easily be formed in a stream channel, but I find great difficulty in explaining their formation on an offshore bar. Mr. Bass mentions a bed of coal above the sand in one place, and I remember similar occurrences. These can be explained by either theory.

Mr. Bass has shown that there are gaps between the individual oil pools and has pointed out that such gaps occur in many places along the coast in various beach and bar forms. The similarity is very apparent on the map, but years ago I examined the well logs in such gaps and found that the dry holes in direct line had sand and ordinarily had showings of oil. An operator who misses a commercial oil well is not much interested in the scientific aspects of the case, and his well log may reflect his feelings at the moment. The currents of a stream carry and deposit sands and muds in accordance with their velocity and could easily cause poor places in an otherwise continuous sand body.

In postulating the beach or bar theory one must have a land mass on one side and a sea on the other. In such a case sediments on one side of the sand body should be different from those on the other side. The beds on either side of a sand-filled stream channel later buried by an advancing sea should be generally similar, and I believe that this is the case much more commonly than not in this area. Since these seas were relatively shallow, sand and sandy shale should extend seaward from the beach for some distance.

A series of facts which Mr. Bass did not mention, but which was touched on by Mr. Holl in his discussion, is that these sand trends have a much greater extent than his map shows. They continue northward into Chase, Lyon, and Coffee counties, and the Teeter trend is found in several places extending southwest into Butler County, which would indicate that it connects with the Haverhill trend. In both of these cases the sands contain water with no oil. This is unfortunate and remarkable as well as unexplained. The southwest end of the Sallyards trend is headed toward the bulge on the middle of the east side of the Fox Bush pool, and there is some evidence suggesting that these connect. It is not difficult to construct a drainage system flowing south from Greenwood and Butler counties through Cowley County into Oklahoma. The granite ridge furnished sands from one side of the broad valley and a large high area extending from north-central Osage in Oklahoma through parts of Cowley, Chautauqua, Elk, Wilson, and Woodson counties in Kansas, formed the other side and separated our valley from the eastern Kansas trough. To speculate further, the Burbank pool might easily be a deposit along the shore into which our stream flowed. It represents fully my idea of a preserved beach form.

The location and distribution of these sand bodies is a convincing argument in favor of the bar theory, but a part of the earlier deposition must have been subject to erosion above the sea-level as well as below it while the later part was in process of deposition. This should have had a tendency to tear up and re-deposit, at least in part, the earlier bar system. This does not seem to have been done. On the other hand, I can not conceive of two drainage systems crossing each other and continuing, each on its own way, unless one was younger than the other and was developed on a different land surface following submergence and re-emergence of the first surface. At the Seely pool, where the two systems cross, Mr. Bass points out that the Teeter Quincy stage is 40 feet lower than the Sallyards trend. This suggests strongly that an old channel was crossed by a younger.

The usual convex shape of the top of the sand bodies is the best argument for the bar theory. A gentle pseudo-structure following the elongate sand bodies can be mapped on the top of the Oswego limestone (300-400 feet above the Bartlesville sand). This apparent structure is due to slumping, settling and compaction of the intervening Cherokee shales around the sand mass. I believe this compaction should have the effect of slightly changing the shape of the top and bottom of the sand bodies. Also wave action in the advancing sea which covered the old land surface could rework the top sands of the former stream channel and thereby cause sand and sandy shale to be deposited above the sand body where muds only were deposited on either side of the former channel. I have noted in wells which I have watched closely that the first indication of Bartlesville sand is ordinarily a poor sandy shale and that the first oil is found at a varying distance below this top. Various operators pick their sand tops at various places in the stratigraphic column, which makes it extremely difficult to map accurately the sand thickness and thereby determine the true shape of the sand body.

To summarize briefly: I have pointed out the difficulties which I personally have to overcome in accepting the bar theory. I have also outlined a possible alternate explanation to which I retreat when the bar difficulties become too great. At present I favor the channel-filling theory, but I do not

DISCUSSION

firmy believe in either one and feel confident that the subject can be explored further to great advantage.

RUSSELL S. TARR

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TULSA, OKLAHOMA
October 23, 1934

FLUID MECHANICS OF SALT DOMES

The comments of E. H. Sellards in the discussion of the writer's paper, "Fluid Mechanics of Salt Domes," in the September *Bulletin*, page 1203, suggest the following.

The mixing of liquids to which Mr. Sellards refers is such as would result from turbulent flow. When flow is stream-line or non-turbulent there is a much smaller tendency for the liquids to become mixed. This can be observed sometimes when a muddy stream flows into a clear one and the line of separation between muddy and clear water is visible for miles below the junction. The greater the viscosity of the fluids involved the less is the tendency for turbulent flow and the greater is the tendency for stream-line flow. If salt and sediments move very slowly as very highly viscous liquids, there would probably be no turbulence at all. In the original paraffine salt-dome model from which Figure 4, page 1189, was made, the lines of flow can be seen clearly and they show stream-line flow without any marked tendency for turbulence or mixing of the different parts or layers of the paraffine. The strata in the Grand Saline salt mine to which Mr. Sellards refers are nearly vertical and are rather similar to the vertical lines in the paraffine model. The writer had this paraffine model with him on the trip to the Grand Saline salt mine after the Dallas meeting last March. The similarity of the stratification in the mine to that of the paraffine model was pointed out at that time to Mr. Judson (who had charge of the trip) and to others, who agreed that the general nature of the flow, as well as could be judged by such a simple comparison, may have been very similar in the dome and in the model.

L. L. NETTLETON

PITTSBURGH, PENNSYLVANIA
October 29, 1934

REVIEWS AND NEW PUBLICATIONS

"Petroleum and Natural Gas in Poland. Volume II—Boryslaw. Part I, Geology. Part II, Production Statistics." By K. TOLWINSKI. *Carpathian Inst. Petrol. Geol. Bull.* 22. Warsaw, Boryslaw, Lwow, 1934. 159 and LXII pp., 41 figs., 5 pls. In Polish and French. Paper. 6.25×9.5 inches.

This work of Dr. Tolwinski is the second volume of monographic studies of the Polish oil fields: the first volume, which deals with a number of oil fields along the northern border of the Carpathians, was published in 1929 (Bulletin 18). In another publication of the Institute, "Petroleum Geology and Statistics in Poland," there appeared several brief monographic studies of oil fields in the Median zone (Potok, Grabownica, Brobrka, Libusza Lipinki, Iwonicz, et cetera) and in the Magura zone. Therefore the work under review completes the description of almost all of the Polish fields. This book is a great credit to the author, who continues to work tirelessly in the field and who succeeded in obtaining the collaboration of several young geologists. The publication of these works, as well as of a number of maps, particularly the "New Geologic Atlas of Boryslaw" (Bulletin 19 (1929-30): structural map, scale 1:5,000; map showing yield, scale 1:10,000; section, 10 colored plates) could be carried out only with the assistance given by the petroleum industry to the Institute which was created by this industry together with the Ministry of Industry and Trade. Moreover, with the assistance of the petroleum industry a systematic research of the chemical composition of Polish crudes has been organized. This work is being done under the supervision of Professor Pilat in the laboratory of Petroleum Technology at the Polytechnic School in Lwow. A part of these analyses was published in 1932, "Analyses of the Polish Crudes."

The work under review comprises a description of the Boryslaw-Tusanowice-Mraznica fields, whereas details regarding various parts of these fields and the inter-relations between the oil-bearing and water-bearing horizons can be found in the aforementioned atlas, and data regarding the chemical composition of the water in the various horizons have already been published in Bulletin 17 (1928) and in Bulletin 20 (1930).

The structure of the Polish Carpathians is interpreted by the author as a system of blocks of a special kind, thrust one upon the other in a definite order. These blocks, some of which are completely detached one from the other, are called "skiba," in order to distinguish them from the "nappes de charriage," for example those of the Alps, which have a completely different character. The word "skiba" means in Polish the clod turned over by the plough. The "skiba" are a sort of scale and this structure is entirely different from the structure of the Alps. However, the author (p. 101) is inclined to consider the Boryslaw structure "as a classical phenomenon of the 'charriage en nappes' (overlapping overthrusts)." This shows that the general ideas of the author have undergone a certain evolution, inasmuch as he recently published an article, "On the Principal Units of the Structure of the Exterior Border Carpathians," which appeared in the volume dedicated to Professor

Romer in connection with the International Geographical Congress at Warsaw in 1934. In this article the author represents the Magura zone as an enormous blanket overthrust extending over the Median zone and even over the western part of the northern region in "skiba" up to the border of the Carpathians in front of Krakow and Wieliczka.

The author gives a very good summary review of the Boryslaw fields (pp. 127-28).¹

In the Boryslaw region the structure of the Carpathian border is divided into several tectonic units or separate blocks which are called "skiba." The overthrust portion of the northern Carpathian border is formed by two "skiba," the border "skiba" and the Orov "skiba," whereas the basement portion is formed of the so-called Boryslaw "skiba." In a longitudinal direction the most important parts structurally are the transverse elevations and the special form of the overthrust "skiba," as well as the form of the basement portion. The accumulation of bituminous deposits depends upon these features. Between the highest portion of the longitudinal axis of the chain, in the region of Boryslaw, and the depressions on both its extremities, particularly in the northwest, there appears a whole series of transversal dislocations in the overthrust elements, as well as in the basement.

The basement portion ("skiba" of Boyslaw) is an independent tectonic unit occupying a large area in the eastern border Carpathians. This unit forms one block similar to the superimposed Carpathian blocks and has the form of an inclined fold with a reduced inverted flank. The detailed study of the Boryslaw "skiba" has for us a great theoretical value, because it constitutes a basement element, as opposed to the higher-lying "skiba," the form of which has been considerably modified, and which have been partly destroyed because these units are outcropping. For instance, the frontal part of the Boyslaw "skiba" has been completely preserved, which is very rarely the case in Poland for tectonic elements of this type.

Neither the fundamental nor the secondary formations of the border unit are directly reflected in the morphological structure of the surface; however, taken as a whole, they are indirectly related to the formation of the exterior border of the Carpathians in our region. In a general way, the highest portions, for example those of the border masses of the Carpathians, correspond to the highest portion of the basement unit.

The colored geological map, scale 1:10,000, and the tectonic map, scale 1:15,000, together with the profiles, give a plastic picture of the structure of the border and Orov "skiba," of the transversal dislocations and of the secondary folds which have a decisive bearing on the distribution of petroleum, gas, and salt water (map of the oil-bearing region in relation to the structure at depth, scale 1:25,000).

Pages 131-149 of the French text contain a stratigraphic description (map of the surroundings of Boryslaw, 1:30,000) and pages 151-59 give a historical sketch of the development of our knowledge of the Boryslaw region. According to the author the entire basin of the Flysch sea, which extended over the original site of the present Carpathian formations (which have a total thickness of about 1,500 meters) was submitted to the rhythmic action of powerful forces. Due to their action, the bottom of the sea was lowered during certain epochs, whereas during other epochs it was raised almost up to the water level. Figure 26 shows in a schematic way these rhythmic changes from the Lower Cretaceous to the Lower Miocene, namely the lowering of the Lower Cretaceous, Lower Eocene and Lower Oligocene basin and its raising during the Upper Cretaceous and Miocene. In fact, these

¹ American readers can consult the map of subsurface structure and the section in an article by the same author: "Natural Gas in Poland," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 7 (July, 1934), pp. 895-96.

processes were sometimes very complicated and in all probability they were also accompanied by orogenic movements. For instance, in many cases we see that the lower part of the Cretaceous is folded more strongly and in discord with the superimposed formations, including the Jamna sandstone.

The principal Carpathian movements which have brought about the overthrusting of the "skiba" took place after the sedimentation of the salt-bearing Miocene clays, because these beds form the most recent stratigraphic level in the Boryslaw folds. Moreover, these folds were thrust over a similar formation, namely, the Pericarpathian zone. Therefore, the principal Carpathian movements took place after the sedimentation of the first Mediterranean stage, or, according to the stratigraphic classification now generally accepted, during the post-Helvetian epoch. However, the later stages of these movements were probably prolonged until the most recent Miocene. According to the author, it is in a southern direction that we must look for the conditions which have changed the character of the materials of the geological formations, even in the basement unit. These conditions naturally exercised a great influence on the development of the organic life in the marine basins, which extended over the area of the present Carpathians, as well as on the appearance and extinction of the fauna and flora, and therefore on the concentration of the bituminous deposits in certain formations.

Part II of the work of Tolwinski, devoted to the Boryslaw statistics, gives the production of all wells to 1932, subdivided according to geological horizons. The Boryslaw fields, having a total area of 1,140 hectares, have given 2,318,751 cars, or 2,061 cars per hectare (58,000 barrels per acre). In 1933 this production reached 60,905 barrels per acre, which is more than the production of the Coalinga and Midway fields, taken together.

Tolwinski's excellent book on the Boryslaw oil fields and his other works, as well as the works of his colleagues in the numerous oil fields of the Polish Carpathians, sufficiently illustrate that the difficult geological conditions for the exploration and exploitation of petroleum reserves are a great obstacle to the development of the petroleum industry, particularly north of Boryslaw in the Carpathian border region, the underground structure of which is still very little known. In spite of our excellent drilling technique, the only defect of which is its slowness, the complicated geology of the Carpathians makes it very doubtful whether every failure in the accomplishment of a previously established plan of petroleum production can be explained exclusively by the technical and managerial defects of drilling, as is being done by the heads of the exploration and exploitation drilling in the U.S.S.R. According to their opinion (I. Gubkin, *The Petroleum Industry*, organ of the Glavnft of U.S.S.R., 1934, Nos. 4, 6 and 7, only in Russian), in the Baku region, in Middle Asia, and in the Volga area "the underground is not responsible for the failures" and all failures, such as were experienced for example in 1933, are due to the unsatisfactory work of the staff and to the "unhealthy" theories of certain geologists. The geological experience of the leaders of the producing branch of the petroleum industry of the U.S.S.R., which in the absence of any other material, as for instance in Middle Asia, is based on the "dialectical method of Marx," may considerably overestimate the richness of the oil deposits of this country.

CHARLES BOHDANOWICZ

WARSAW
October, 1934

RECENT PUBLICATIONS

GENERAL

"A Laboratory Manual of Physical and Historical Geology," by Kirtley F. Mather and Chalmer J. Roy. *The Century Earth Science Series* (D. Appleton-Century Company, New York, 1934). 302 pp., 46 figs., 20 pls. Twenty exercises designed for college students beginning geology; intended for use with the textbook *Earth History* by L. C. Snider. Paper cover and pages perforated for notebook binder. Size, 8.375×10.75 inches.

"Geology and Technology Go Forward," by Stanley C. Herold. *Petrol. World* (Los Angeles, California) *Annual Statistical Review* (November, 1934), pp. 32-44; 27 illustrations.

GEOPHYSICS

"Geophysical Prospecting, 1934," by many authors. *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 110 (1934). 583 pp., illus. Cloth. Outside dimensions, 6.25×9.25 inches. Price, net, \$5.00.

LOUISIANA

"Engineering Studies and Results of Acid Treatment of Wells, Zwolle Oil Field, Sabine Parish, Louisiana," by R. E. Heithecker. *U. S. Bur. Mines R. I. 3251* (October, 1934). 35 mimeogr. pp., 12 tables, 14 figs. Size, 8×10.5 inches.

OKLAHOMA

"Geology and Economic Significance of the Lucien Field," by Basil B. Zavoico. *World Petroleum* (New York), Vol. 5, No. 11 (November, 1934), pp. 416-24; 6 illustrations (4 in color).

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The eleventh annual convention of the Pacific Section of the Association, held at Los Angeles, November 8 and 9, included in its technical program the following papers: "Geology of Santa Rosa Island," by GRAHAM MOODY; "Results of Studies on Organic Content of California Rocks," by PARKER D. TRASK; "Notes on the Franciscan," by N. L. TALIAFERRO; "A Trip Across Arabia," by J. C. NOMLAND; "Tertiary History of a Part of the Transverse Ranges," by R. D. REED; "The Vaqueros in the Temblor Range," by L. M. CLARK and ALEX CLARK; "Discussion of Miocene History and Faunas," by R. M. KLEINPELL; "The Oligocene Problem," by HUBERT SCHENCK; "The Mountain View Oil Field," by K. L. Gow; "The Edison Area," by E. B. NOBLE and W. D. KLEINPELL; "Origin of Glauconite," by WAYNE GALLIGHER; "Progress of the State Geologic Map of California," by OLAF P. JENKINS.

HARRY L. BERRY is geologist for the Harper-Turner Oil Company, Hightower Building, Oklahoma City.

JACK J. BERRY and PHILLIP BERRY are doing general geological work independently in Oklahoma and Texas. Their office is Box 836, Cushing, Oklahoma.

J. E. BRANTLY is president of the Drilling and Exploration Company, Inc., First National Bank Building, Dallas, Texas.

RICHARD T. SHORT is employed by the French Oil Corporation, Laredo, Texas.

CHARLES F. BASSETT, formerly engaged in subsurface work in the Bolivar coastal fields of the Maracaibo Basin in Venezuela, has been working on an underground water survey in the Michigan State forests during the past two years. His address is Hinckley, Illinois.

LESLIE BOWLING, of Austin, Texas, is with the Standard Oil Company of Venezuela at Caripito, Venezuela.

C. W. TOMLINSON, of Ardmore, Oklahoma, presented a paper on the "Pennsylvanian of Southern Oklahoma," before the North Texas Geological Society, Wichita Falls, Texas, November 9.

ALFRED P. FREY, formerly with the Caribbean Petroleum Company, Maracaibo, Venezuela, may now be addressed at 66 Sonneggstrasse, Zurich 6, Switzerland.

WALLACE LEE has changed his address from Graham, Texas, to Box 446, Okmulgee, Oklahoma.

JOHN A. McCUTCHIN, district exploitation engineer for Shell Petroleum Corporation, has been transferred from Pampa, Texas, to Tulsa, Oklahoma.

W. H. BUTT, formerly of Asheville, North Carolina, is now at 3428 Stanford Street, Dallas, Texas.

M. M. KORNFELD announces the opening of a paleontological laboratory at 718 Petroleum Building, Houston, Texas, devoted exclusively to microscopic examination of oil-well cuttings and cores.

GEORGE A. WEAVER, formerly of 741 Ratcliff Street, Shreveport, Louisiana, may now be addressed at 1006 South Jennings Avenue, Fort Worth, Texas.

P. H. REAGAN, formerly of Nevada City, California, is mining geologist with The Fresnillo Company, Fresnillo, Est. de Zac., Mexico.

O. F. HEDRICK, geologist for the Texas Pacific Coal and Oil Company, has been transferred from Thurber to Midland, Texas.

RALPH ILSLEY has changed his address from Cambridge, Massachusetts, to 1734 New York Avenue, Room 601, Washington, D.C.

WILLIAM B. HEROV, chief geologist of the Consolidated Oil Corporation, New York City, made his Association presidential trip to local geological societies in November. His itinerary included: the Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, November 5; the Pacific Section, Los Angeles, California, November 8 and 9; executive committee meeting, Dallas, Texas, November 15; San Antonio Section, November 20; Tulsa Geological Society, Tulsa, Oklahoma, November 22; Ponca City geologists, Ponca City, Oklahoma, November 22; and Kansas Geological Society, Wichita, Kansas, November 23. His trip also included northern Mexico and a visit to the Tri-State zinc and lead mining district of Oklahoma, Kansas, and Missouri. Past-president FRANK R. CLARK and business manager J. P. D. HULL accompanied the president to Wichita to meet with the committee on arrangements for the 20th annual meeting, which will be held at the Allis Hotel, Wichita, Kansas, March 21, 22, and 23, 1935.

INDEX TO VOLUME 18

Adkins, W. S., Sellards, E. H., and Plummer, F. B. The Geology of Texas, Vol. I, Stratigraphy. Review by Ed. W. Owen 554

Adler, Joseph L., and Rosaire, E. E. Applications and Limitations of Dip Shooting 119

Aerial Survey Operations in Australia During 1932, Report on. By W. G. Woolnough. Review by W. P. Woodring 380

Age of Gulf Border Salt Deposits. By Levi S. Brown 1227

— of Jackfork and Stanley Formations of Ouachita Geosyncline, Arkansas and Oklahoma, as Indicated by Plants. By David White 1010

— of So-Called Hunton Limestone of Southern McPherson and Northwest Harvey Counties, Kansas. Discussion by Roy Hall 266

Air Blowers, Craters Formed by. Geological Note by W. Armstrong Price 813

Alberta, Structure of Turner Valley Gas and Oil Field. By Theodore Link and P. D. Moore 1417

Alberta Shale in Foothills of Southwestern Alberta, Zones in. By J. B. Webb and L. G. Hertlein 1387

American Association of Petroleum Geologists, Code of Ethics of The. The Association Round Table 964

—, Nineteenth Annual Meeting, Baker Hotel, Dallas, Texas, March 22-24, 1934. The Association Round Table 154, 274, 673

American Salt Domes, Origin of the Anhydrite Cap Rock of. By Marcus I. Goldman. Review by Donald C. Barton 269

Analyses of Woodbine Cores for Presence of Salt Water. Geological Note by R. H. Fash 265

Angewandte Geophysik für Bergleute und Geologen, I Teil (Practical Geophysics for Engineers and Geologists, Part 1). By Hermann Reich. Review by L. Y. Faust 149

Anhydrite Cap Rock of American Salt Domes, Origin of the. By Marcus I. Goldman. Review by Donald C. Barton 269

Anhydrite-Gypsum Problem of Blaine Formation, Oklahoma. By J. Lawrence Muir 1297

Annual Business Meeting, Minutes of. The Association Round Table 684

Anticline, Tectonics of Oklahoma City. By Lyndon L. Foley 251

Applications and Limitations of Dip Shooting. By E. E. Rosaire and Joseph L. Adler 119

Applications of Geothermics to Geology, Some Possible. By C. E. Van Orstrand 13

Arbuckle Mountains, Oklahoma, Granite and Limestone Velocity Determinations in. By B. B. Weatherby, W. T. Born, and R. L. Harding 106

—, Overthrusting in. By Robert H. Dott 367

Arkansas, Missouri, and Oklahoma, Osage Formations of Southern Ozark Region. By L. M. Cline 1132

Arkansas and Oklahoma, Age of Jackfork and Stanley Formations of Ouachita Geosyncline, as Indicated by Plants. By David White 1010

Arkansas and Oklahoma Coal Fields, Correlations of Pennsylvanian Strata in. By T. A. Hendricks and C. B. Read 1050

Arkell, W. J. The Jurassic System in Great Britain. Review by R. D. Reed 268

Association Committees 156, 276, 427, 559, 714, 842, 966, 1100, 1221, 1382, 1553, 1718

Association Meetings. The Association Round Table 154, 274, 673, 684, 713, 834

Association of Petroleum Geologists, Nineteenth Annual Meeting, Dallas, March 22-24 154, 274, 673

Association Round Table, The 154, 274, 384, 558, 672, 831, 963, 1099, 1219, 1381, 1552, 1717

At Home and Abroad 157, 279, 432, 563, 716, 843, 969, 1101, 1223, 1383, 1555, 1719

Aufsuchung von Wasser mit Geophysikalischen Methoden (Prospecting for Water with Geophysical Methods). By J. Koenigsberger. Review by L. Y. Faust 1375

Australia, Report on Aerial Survey Operations in, During 1932. By W. G. Woolnough. Review by W. P. Woodring	380
Australia and New Guinea, Natural Gas in. By W. G. Woolnough	226
Austria and Neighboring Territory, Geological Map of the Republic of. Hermann Vettler, compiler. Review by Walter M. Small	1375
Avery, C. Dwight, and Miller, J. Charles. Relationship of Geology to Unit Operation of Oil and Gas Fields Involving Government Lands	1454
Barbat, W. F., and Galloway, John. San Joaquin Clay, California	476
Barnegat Inlet, A Study of. By John B. Lucke. Review by John L. Rich	1208
Barnes, R. M. Memorial of D. Bruce Seymour	1222
Barometric Surveying, Corrections for Temperature in. Geological Note by John L. Rich	133
Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas. Discussion by Russell S. Tarr	1710
Origin of. By N. W. Bass	1313
Barton, Donald C. Discussion of Conversion of Fatty and Waxy Substances into Petroleum Hydrocarbons, by W. F. Seyer	143
Magnetic and Torsion-Balance Survey of München Tertiary Basin, Bavaria	69
Research Committee. The Association Round Table	834
Review of <i>Deutsches Erdöl, II</i> , by A. Moos, H. Steinbrecher, and O. Stutzer	1092
Review of Origin of the Anhydrite Cap Rock of American Salt Domes, by Marcus I. Goldman	269
Base Exchange in Relation to Composition of Clay with Special Reference to Effect of Sea Water. By W. P. Kelley and G. F. Liebig, Jr.	358
Basin System of Hungary, Tectonics and Paleogeography of, as Elucidated by Drilling for Oil. By L. De Lóczy	925
Bass, N. W. Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas	1313
Bavaria, Magnetic and Torsion-Balance Survey of München Tertiary Basin. By Donald C. Barton	69
Belgium and Belgian Congo, Oil Possibilities of. By Sylvain J. Pirson	1160
Bendian, Carboniferous Stratigraphy of the Ouachitas with Special Study of the. By Bruce H. Harlton	1018
Blaine Formation, Oklahoma, Anhydrite-Gypsum Problem of. By J. Lawrence Muir	1297
Blau, L. W. Review of <i>Lehrbuch der Angewandten Geophysik. Geophysikalische Aufschlussmethoden</i> (Textbook of Applied Geophysics. Geophysical Methods of Exploration), by Hans Haalck	1374
Bohdanowicz, Charles. Natural Gas Occurrences in Russia (U.S.S.R.)	746
Review of Petroleum and Natural Gas in Poland. Volume II—Borysław. Part I, Geology. Part II, Production Statistics, by K. Tolwinski	1713
Born, W. T., Weatherby, B. B., and Harding, R. L. Granite and Limestone Velocity Determinations in Arbuckle Mountains, Oklahoma	106
Boswell, P. G. H. On the Mineralogy of Sedimentary Rocks—A Series of Essays and a Bibliography. Review by G. S. Dillé	267
Botset, H. G., Wyckoff, R. D., Muskat, M., and Reed, D. W. Measurement of Permeability of Porous Media	161
Brace, O. L. Factors Governing Estimation of Recoverable Oil Reserves in Sand Fields	343
Brace, O. L., Deussen, Alexander, Pepperberg, Leon J., Thompson, W. C., Clark, S. K., Wilde, Jr., H. D., and Moore, T. V. Factors Governing Estimation of Recoverable Oil Reserves in Sand Fields. Discussion	1078
Bradford Sand, Bradford Field, Pennsylvania, Physical Characteristics of, and Relation to Production of Oil. By Charles R. Fettke	191
Brainerd, A. E., and Johnson, J. Harlan. Mississippian of Colorado	531
Bramlette, W. M. Heavy Mineral Studies on Correlation of Sands at Kettleman Hills, California	1559
British Somaliland, The Geology of. By W. A. Macfadyen. Review by Margaret C. Cobb	1212
Brown, Levi S. Age of Gulf Border Salt Deposits	1227

INDEX TO VOLUME 18

1723

Buchanan, George S. Discovery of Valentine (La Rose) Dome, Louisiana, by Reflection Seismograph. Geological Note	543
Bucher, Walter H. Review of <i>Die Orogentheorie</i> , by L. Kober	824
—. The Deformation of the Earth's Crust. Review by Ralph Stewart	1093
Bucher, Walter I., <i>et al.</i> Catalogue of Small Scale Geological Maps, 1933. Review by A. I. Levorsen	1208
Bullard, Jesse L. Review of National Oil Scouts Association Year Book, 1934	1213
Burma, Natural Gas Fields of. By L. Dudley Stamp	315
Business Meeting, Minutes, Baker Hotel, Dallas, Texas, March 22-24, 1934. The Association Round Table	684
California, Geology of Huntington Beach Oil Field. By Hoyt S. Gale	327
—, Heavy Mineral Studies on Correlation of Sands at Kettleman Hills. By W. M. Bramlette	1559
—, Preliminary Study of Source Beds in Late Mesozoic Rocks on West Side of Sacramento Valley. By Parker D. Trask and Harald E. Hammar	1346
—, San Joaquin Clay. By W. F. Barbat and John Galloway	476
—, Subsurface Stratigraphy of Kettleman Hills Oil Field. By Paul P. Goudkoff	435
Canada, Oil and Gas in Western (2d ed.). By G. S. Hume. Review by Theodore A. Link	551
Cap Rock, Anhydrite, of American Salt Domes, Origin of the. By Marcus I. Goldman. Review by Donald C. Barton	269
—, Occurrence of Siderite in, at Carlos Dome, Grimes County, Texas. Geological Note by F. W. Rolshausen	543
—, Rôle of, in Oil Accumulation. Discussion by C. L. Dake and L. F. Dake	1086
Carboniferous Rocks of Ouachita Mountains. By Hugh D. Miser	971
Carboniferous Stratigraphy of the Ouachitas with Special Study of the Bendian. By Bruce H. Harlton	1018
Carlos Dome, Grimes County, Texas, Occurrence of Siderite in Cap Rock at. Geological Note by F. W. Rolshausen	543
Cartographic Terminology, Difficulty of Using in Historical Geology. Geological Note by R. M. Kleinpell	374
Catalogue of Small Scale Geological Maps, 1933. By Walter H. Bucher, <i>et al.</i> Review by A. I. Levorsen	1208
Caucasus, Tectonics of Southeastern, and Its Relation to the Productive Oil Fields. By I. M. Goubkine	603
Characteristics of Organic Content of Rocks, Some. By William L. Russell	1103
Chitani, Yoshinosuki. Petroleum Resources of Japan	908
Chugwater, Lower, of Central and Southeastern Wyoming, Phosphoria and Dindwoody Tongues in. By Horace D. Thomas	1655
Cinnabar Mountain, Park County, Montana, and Mount Everts, Yellowstone National Park, Wyoming, Section of Paleozoic and Mesozoic Rocks Measured at. Geological Note by Charles W. Wilson, Jr.	368
Clark, S. K., Deussen, Alexander, Brace, O. L., Pepperberg, Leon J., Thompson, W. C., Wilde, Jr., H. D., and Moore, T. V. Factors Governing Estimation of Recoverable Oil Reserves in Sand Fields. Discussion	1078
Clay, Base Exchange in Relation to Composition of, with Special Reference to Effect of Sea Water. By W. P. Kelley and G. F. Liebig, Jr.	358
Cline, L. M. Osage Formations of Southern Ozark Region, Missouri, Arkansas, and Oklahoma	1132
Coal Fields, Correlations of Pennsylvanian Strata in Arkansas and Oklahoma. By T. A. Hendricks and C. B. Read	1050
Coalification Theory of Origin of Oil and Gas. Discussion by F. M. Van Tuyl and Ben H. Parker	1547
Cobb, Margaret C. Review of The Geology of British Somaliland, by W. A. Macfadyen	1212
Code of Ethics of The American Association of Petroleum Geologists. The Association Round Table	964
Colorado, Geology of Two Buttes Dome in Southeastern. By C. W. Sanders	860
—, Geology of Two Buttes Dome in Southeastern. Discussion by Ben H. Parker and C. W. Sanders	1544
—, Mississippian of. By A. E. Brainerd and J. Harlan Johnson	531

_____, Type Section of Hermosa Formation. Geological Note by Robert Roth <i>Compilación de los Estudios Geológicos Oficiales en Colombia, 1917 a 1933, Tomo I</i> (Compilation of the Official Geological Studies in Colombia, 1917 to 1933, Vol. I). By Roberto Scheib. Review by Robert H. Dott	944
Composition of Clay, Base Exchange in Relation to, with Special Reference to Effect of Sea Water. By W. P. Kelley and G. F. Liebig, Jr.	1377
Condit, D. Dale. Natural Gas and Oil in India	358
Constitution and By-Laws. The Association Round Table	283
Conversion of Fatty and Waxy Substances into Petroleum Hydrocarbons. By W. F. Seyer. Discussion by Donald C. Barton	835
Correction to Stratigraphy of Hoxbar Formation, Oklahoma. Discussion by C. W. Tomlinson	143
Corrections for Temperature in Barometric Surveying. Geological Note by John L. Rich	1083
Correlation of Pecan Gap Chalk in Texas. By Alva C. Ellisor and John Teagle _____- of Sands at Kettleman Hills, California, Heavy Mineral Studies on. By W. M. Bramlette	133 1506
Correlations of Pennsylvanian Strata in Arkansas and Oklahoma Coal Fields. By T. A. Hendricks and C. B. Read	1559
Craters Formed by Air Blowers. Geological Note by W. Armstrong Price	1050
Cretaceous Beds of Prowers County, Colorado, Fossil Sink Holes in. By Carle H. Dane and W. G. Pierce	813
Cumberland Thrust Block, Virginia, Kentucky, and Tennessee. Mechanics of Low-Angle Overthrust Faulting as Illustrated by. By John L. Rich	1493
Curry, Jr., William H. Fredericksburg-Washita (Edwards-Georgetown) Con- tact in Edwards Plateau Region of Texas. Geological Note	1584
Dake, C. L. Review of Outlines of Physical Geology, by Chester R. Longwell, Adolph Knopf, and Richard F. Flint	1698 960
Dake, C. L. and L. F. Rôle of Cap Rock in Oil Accumulation. Discussion	1086
Daly, Reginald Aldworth. Igneous Rocks and the Depths of the Earth. Review by L. C. Snider	151
Dane, Carle H., and Pierce, W. G. Fossil Sink Holes in Cretaceous Beds of Prowers County, Colorado	1493
Davies, A. Morley. Tertiary Faunas. Vol. II, The Sequence of Tertiary Faunas. Review by Alva C. Ellisor	1206
de Cizancourt, H. Review of <i>Gisement pétrolifères de l'Iraq</i> (The Petroliferous Beds of Iraq), by C. P. Niclesco	381
Deformation of the Earth's Crust, The. By Walter H. Bucher. Review by Ralph Stewart	1093
De Lóczy, L. Tectonic and Paleogeography of Basin System of Hungary as Elucidated by Drilling for Oil	925
Depth and Thickness of Strata. Discussion by W. Armstrong Price	817
Depths Less than One Hundred Feet, Earth Resistivities at. By W. D. Keller	39
Depths of the Earth, Igneous Rocks and the. Reginald Aldworth Daly. Review by L. C. Snider	151
Deussen, Alexander. Oil-Producing Horizons of Gulf Coast in Texas and Lou- isiana	500
_____. Two Decades of Progress in the Art of Oil Finding. Geological Note	942
Deussen, Alexander, Brace, O. L., Pepperberg, Leon J., Thompson, W. C., Clark, S. K., Wilde, Jr., H. D., and Moore, T. V. Factors Governing Es- timation of Recoverable Oil Reserves in Sand Fields. Discussion	1078
<i>Deutsches Erdöl, II.</i> By A. Moos, H. Steinbrecher, and O. Stutzer. Review by Donald C. Barton	1092
Difficulty of Using Cartographic Terminology in Historical Geology. Geological Note by R. M. Kleinpell	374
Dillé, G. S. Review of On the Mineralogy of Sedimentary Rocks—A Series of Essays and a Bibliography, by P. G. H. Boswell	267
Dinwoody and Phosphoria Tongues in Lower Chugwater of Central and South- eastern Wyoming. By Horace D. Thomas	1655
Dip Shooting, Applications and Limitations of. By E. E. Rosaire and Joseph L. Adler	119
Discovery of Valentine (La Rose) Dome, Louisiana, by Reflection Seismograph.	

INDEX TO VOLUME 18

1725

Geological Note by George S. Buchanan 543
 Discussion 143, 266, 547, 817, 948, 1078, 1544, 1710
 Dott, Robert H. Overthrusting in Arbuckle Mountains, Oklahoma 567
 —. Review of *Compilación de los Estudios Geológicos Oficiales en Colombia, 1917 a 1933, Tomo I* (Compilation of the Official Geological Studies in Colombia, 1917 to 1933, Vol. I), by Roberto Scheib 1377
 —. Review of Petroleum Development and Technology, 1934, by Petroleum Division, Trans. Amer. Min. Met. Eng., Vol. 107 1378

Earth, Physics of the. VI. Seismology. By the Subsidiary Committee on Seismology, Division of Physical Sciences, with the Coöperation of the Division of Geology and Geography, and the American Geophysical Union. Review by B. B. Weatherby 1205
 Earth, Radio and the Stars. By Harlan True Stetson. Review by C. E. Van Orstrand 1209
 Earth Resistivities at Depths Less than One Hundred Feet. By W. D. Keller 39
 Earth's Crust, The Deformation of the. By Walter H. Bucher. Review by Ralph Stewart 1093
 Edwards, Everett C. Pliocene Conglomerates of Los Angeles Basin and Their Paleogeographic Significance 786
 Edwards Plateau Region of Texas, Fredericksburg-Washita (Edwards-Georgetown) Contact In. Geological Note by William H. Curry, Jr. 1698
 Ellisor, Alva C. Review of Tertiary Faunas. Vol. II, The Sequence of Tertiary Faunas, by A. Morley Davies 1206
 Ellisor, Alva C., and Teagle, John. Correlation of Pecan Gap Chalk in Texas En Échelon Faults in Oklahoma. By William B. Kramer 1506
 En Échelon Dome, Liberty County, Texas. By W. L. Goldston and George D. Stevens 243
 Estimation of Recoverable Oil Reserves in Sand Fields, Factors Governing. By O. L. Brace 1632
 Ethics of The American Association of Petroleum Geologists, Code of. The Association Round Table 343
 European Oil and Gas Occurrences and Their Relationship to Structural Conditions. By H. Stille and H. Schlüter 964
 Evans, Louis H. Memorial of John R. Roberts 736
 Executive Committee Meeting, Dallas, Texas, March 20 and 24, 1934. The Association Round Table 277
 Explanation for Large Amounts of Gas in Anderson and Leon Counties, Texas. Geological Note by Russell S. Tarr 713
 Factors Governing Estimation of Recoverable Oil Reserves in Sand Fields. By O. L. Brace 263
 —. Discussion by Alexander Deussen, O. L. Brace, Leon J. Pepperberg, W. C. Thompson, S. K. Clark, H. D. Wilde, Jr., and T. V. Moore 343
 Fash, R. H. Analyses of Woodbine Cores for Presence of Salt Water. Geological Note 1078
 Faults, En Échelon, in Oklahoma. By William B. Kramer 265
 Faust, L. Y. Review of *Angewandte Geophysik für Bergleute und Geologen, I Teil* (Practical Geophysics for Engineers and Geologists, Part 1), by Hermann Reich 243
 —. Review of *Aufsuchung von Wasser mit Geophysikalischen Methoden* (Prospecting for Water with Geophysical Methods), by J. Koenigsberger 149
 Fettke, Charles R. Physical Characteristics of Bradford Sand, Bradford Field, Pennsylvania, and Relation to Production of Oil 1375
 Field, Richard Montgomery. The Principles of Historical Geology from the Regional Point of View. Review by Robert Roth 191
 Financial Statement, 1933. The Association Round Table 553
 Flint, Richard F., Longwell, Chester R., and Knopf, Adolph. Outlines of Physical Geology. Review by C. L. Dake 385
 Fluid Mechanics of Salt Domes. By L. L. Nettleton 960
 —. Discussion by L. L. Nettleton 1175
 Foley, Lyndon L. Review of Petroleum Production Engineering, Oil Field Development (2d. ed.), by Lester Charles Uren 1712
 —. 961

INDEX TO VOLUME 18

_____. Tectonics of Oklahoma City Anticline	251
Foreword to Symposium on Geophysics. By B. B. Weatherby	1
Formulas for Calculating Stratigraphic Thickness Exposed Between Two Dips	139
Geological Note by E. L. Ickes	1493
Fossil Sink Holes in Cretaceous Beds of Prowers County, Colorado. By Carle H. Dane and W. G. Pierce	519
Fox, McFaddin-O'Conner, Greta, Refugio, White Point, and Saxet Fields, Texas. By A. E. Getzendaner	1698
Fredericksburg-Washita (Edwards-Georgetown) Contact in Edwards Plateau Region of Texas. Geological Note by William H. Curry, Jr.	327
Gale, Hoyt S. Geology of Huntington Beach Oil Field, California	476
Galloway, John, and Barbat, W. F. San Joaquin Clay, California	871
Gardescu, Ionel I. Geology of Natural Gas in Roumania	519
Gas, An Explanation for Large Amounts in Anderson and Leon Counties, Texas. Geological Note by Russell S. Tarr	263
_____, Natural, and Oil in India. By D. Dale Condit	283
_____, Natural, in Australia and New Guinea. By W. G. Woolnough	226
Gas and Oil in India, Natural. By D. Dale Condit	283
_____, in Western Canada (2nd ed.). By G. S. Hume. Review by Theodore A. Link.	551
Gas Fields, Natural, of Burma. By L. Dudley Stamp	315
Geologic History at a Glance. By L. W. Richards and G. L. Richards, Jr. Review by William S. W. Kew	1213
Geologic Structures, 3d ed. By Bailey and Robin Willis. Review by J. V. Howell	1549
Geological Map of the Republic of Australia and Neighboring Territory. Hermann Vettler, compiler. Review by Walter M. Small	1375
Geological Maps, Catalogue of Small Scale, 1933. By Walter H. Bucher, et al. Review by A. I. Levorsen	1208
Geological Notes	133, 263, 368, 543, 813, 942, 1537, 1698
Geology, Historical. By Walter August Ver Wiebe. Review by Roy H. Hall	1550
_____, of British Somaliland. By W. A. Macfadyen. Review by Margaret C. Cobb	1212
_____, of Huntington Beach Oil Field, California. By Hoyt S. Gale	327
_____, of Natural Gas in Roumania. By Ionel I. Gardescu	871
_____, of Texas, The, Vol. I, Stratigraphy. By E. H. Sellards, W. S. Adkins, and F. B. Plummer. Review by Ed. W. Owen	554
_____, of Two Buttes Dome in Southeastern Colorado. By C. W. Sanders	860
_____, of Two Buttes Dome in Southeastern Colorado. Discussion by Ben H. Parker and C. W. Sanders	1544
_____, Outlines of Physical. By Chester R. Longwell, Adolph Knopf, and Richard F. Flint. Review by C. L. Dako	960
_____, Relations of Geophysics to. By Paul Weaver	3
_____, Some Possible Applications of Geothermics to. By C. E. Van Orstrand	13
_____, The Principles of Historical, from the Regional Point of View. By Richard Montgomery Field. Review by Robert Roth	719
Geophysics, Foreword to Symposium. By B. B. Weatherby	553
_____, Relations to Geology. By Paul Weaver	1
Geothermics, Some Possible Applications to Geology. By C. E. Van Orstrand	3
Germany, Natural Gas Occurrences of. By H. Stille and H. Schlüter	13
Getzendaner, A. E. McFaddin-O'Conner, Greta, Fox, Refugio, White Point, and Saxet Fields, Texas	519
Gisement pétrolier de Iraq (The Petroliferous Beds of Iraq). By C. P. Niculesco. Review by H. de Cizancourt	381
Goldman, Marcus I. Origin of the Anhydrite Cap Rock of American Salt Domes. Review by Donald C. Barton	269
Goldston, W. L., and Stevens, George D. Esperson Dome, Liberty County, Texas	1632
Goubkin, I. M. Tectonics of Southeastern Caucasus and Its Relation to the Productive Oil Fields	603
Goudkoff, Paul P. Subsurface Stratigraphy of Kettleman Hills Oil Field, California	435

INDEX TO VOLUME 18

1727

Granite and Limestone Velocity Determinations in Arbuckle Mountains, Oklahoma. By B. B. Weatherby, W. T. Born, and R. L. Harding	106
Great Britain, The Jurassic System in. By W. J. Arkell. Review by R. D. Reed	268
Greta, McFaddin-O'Conner, Fox, Refugio, White Point, and Saxet Fields, Texas. By A. E. Getzendaner	519
Gulf Border Salt Deposits, Age of. By Levi S. Brown	1227
Gulf Coast in Texas and Louisiana, Oil-Producing Horizons of. By Alexander Deussen	500
Haalck, Hans. <i>Lehrbuch der Angewandten Geophysik. Geophysikalische Aufschlussmethoden</i> (Textbook of Applied Geophysics, Geophysical Methods of Exploration). Review by L. W. Blau	1374
Hall, Roy H. Age of So-Called Hunton Limestone of Southern McPherson and Northwest Harvey Counties, Kansas. Discussion	266
—. Review of Historical Geology, by Walter August Ver Wiebe	1550
Hammar, Harald E., and Trask, Parker D. Preliminary Study of Source Beds in Late Mesozoic Rocks on West Side of Sacramento Valley, California	1346
Hammer, A. A. Rattlesnake Hills Gas Field, Benton County, Washington	847
Hanna, Marcus A., and Wolf, Albert G. Texas and Louisiana Salt-Dome Cap-Rock Minerals	212
Harding, R. L., Weatherby, B. B., and Born, W. T. Granite and Limestone Velocity Determinations in Arbuckle Mountains, Oklahoma	106
Harlton, Bruce H. Carboniferous Stratigraphy of the Ouachitas with Special Study of the Bendian	1018
Haynes, W. P. Review of Proceedings World Petroleum Congress	822
Heavy Mineral Studies on Correlation of Sands at Kettleman Hills, California. By W. M. Bramlette	1559
Hendricks, T. A., and Read, C. B. Correlations of Pennsylvanian Strata in Arkansas and Oklahoma Coal Fields	1050
Henson, F. R. S. Portable Sedimentary Laboratory. Geological Note	1705
Hermosa Formation, Colorado, Type Section of. Geological Note by Robert Roth	944
Hertlein, L. G., and Webb, J. B. Zones in Alberta Shale in Foothills of Southwestern Alberta	1387
Historical Geology. By Walter August Ver Wiebe. Review by Roy H. Hall	1550
—. Difficulty of Using Cartographic Terminology in. Geological Note by R. M. Kleinpell	374
—. The Principles of, from the Regional Point of View. By Richard Montgomery Field. Review by Robert Roth	553
Hoover, James Earl. Memorial by Charles T. Kirk	430
Hopkins, Oliver B. Memorial of J. Lauer Stauff	715
Hornsberger, Thomas Kennerly. Memorial by Roscoe E. Shutt	1554
Howell, J. V. Review of Geologic Structures, 3d ed., by Bailey and Robin Willis	1549
Howell, Lynn G. Radioactivity of Soil Gases	63
Hoxbar Formation, Oklahoma, Correction to Stratigraphy of. Discussion by C. W. Tomlinson	1083
Hume, G. S. Oil and Gas in Western Canada. Review by Theodore A. Link	551
Hungary, Tectonics and Paleogeography of Basin System of, as Elucidated by Drilling for Oil. By L. De Lóczy	925
Huntington Beach Oil Field, California, Geology of. By Hoyt S. Gale	327
Hunton Limestone, Age of So-Called, of Southern McPherson and Northwest Harvey Counties, Kansas. Discussion by Roy Hall	266
Ickes, E. L. Formulas for Calculating Stratigraphic Thickness Exposed Between Two Dips. Geological Note	139
Igneous Rocks and the Depths of the Earth. By Reginald Aldworth Daly. Review by L. C. Snider	151
India, Natural Gas and Oil in. By D. Dale Condit	283
Iraq, <i>Gisement pétrolifères</i> (The Petroliferous Beds of Iraq). By C. P. Nicolesco. Review by H. de Cizancourt	381
Jackfork and Stanley Formations of Ouachita Geosyncline, Arkansas and Oklahoma, Age of, as Indicated by Plants. By David White	1010

INDEX TO VOLUME 18

Jamin Effect in Oil Production. Discussion by J. Versluys	547
Japan, Petroleum Resources of. By Yoshinosuki Chitani	908
Jenny, W. P. Magnetic Vector Study of Kentucky and Southern Michigan	97
Johnson, J. Harlan, and Brainerd, A. E. Mississippian of Colorado	531
Jurassic System in Great Britain, The. By W. J. Arkell. Review by R. D. Reed	268
Kansas, Age of So-Called Hunton Limestone, of Southern McPherson and Northwest Harvey Counties. Discussion by Roy Hall	266
—, Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties. By N. W. Bass	1313
—, Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas. Discussion by Russell S. Tarr	1710
Keller, W. D. Earth Resistivities at Depths Less than One Hundred Feet	39
Kelley, W. P., and Liebig, Jr., G. F. Base Exchange in Relation to Composition of Clay with Special Reference to Effect of Sea Water	358
Kentucky, Notes on Origin of Oil in. By William L. Russell	1126
Kentucky and Southern Michigan, Magnetic Vector Study of. By W. P. Jenny	97
Kentucky, Virginia, and Tennessee, Mechanics of Low-Angle Overthrust Faulting as Illustrated by Cumberland Thrust Block. By John L. Rich	1584
Kettleman Hills, California, Heavy Mineral Studies on Correlation of Sands at. By W. M. Bramlette	1559
Kettleman Hills Oil Field, California, Subsurface Stratigraphy of. By Paul P. Goudkoff	435
Kew, William S. W. Memorial of Eric A. Starke	967
—. Review of Geologic History at a Glance, by L. W. Richards and G. L. Richards, Jr.	1213
King, Philip B. Notes on Upper Mississippian Rocks in Trans-Pecos Texas. Geological Note	1537
Kirk, Charles T. Memorial of James Earl Hoover	430
Kleinpell, R. M. Difficulty of Using Cartographic Terminology in Historical Geology. Geological Note	374
Knopf, Adolph, Longwell, Chester R., and Flint, Richard F. Outlines of Physical Geology. Review by C. L. Dake	960
Kober, L. <i>Die Orogentheorie</i> . Review by Walter H. Bucher	824
Koenigsberger, J. <i>Aufsuchung von Wasser mit Geophysikalischen Methoden</i> (Prospecting for Water with Geophysical Methods). Review by L. Y. Faust	1375
Kramer, William B. En Echelon Faults in Oklahoma	243
—. Permian Ledge-Makers in Concho County, Texas	1577
Ledge-Makers, Permian, in Concho County, Texas. By William Kramer	1374
<i>Lehrbuch der Angewandten Geophysik. Geophysikalische Aufschlussmethoden</i> (Textbook of Applied Geophysics. Geophysical Methods of Exploration). By Hans Haalck. Review by L. W. Blau	1208
Levorsen, A. I. Review of Catalogue of Small Scale Geological Maps, 1933, by Walter H. Bucher, et al	358
Liebig, Jr., G. F., and Kelley, W. P. Base Exchange in Relation to Composition of Clay with Special Reference to Effect of Sea Water	266
Limestone, Age of So-Called Hunton, of Southern McPherson and Northwest Harvey Counties, Kansas. Discussion by Roy Hall	106
Limestone and Granite Velocity Determinations in Arbuckle Mountains, Oklahoma. By B. B. Weatherby, W. T. Born, and R. L. Harding	119
Limitations and Applications of Dip Shooting. By E. E. Rosaire and Joseph L. Adler	551
Link, Theodore A. Review of Oil and Gas in Western Canada, by G. S. Hume	1417
Link, Theodore, and Moore, P. D. Structure of Turner Gas and Oil Field, Alberta	948
Lissie Formation and Beaumont Clay in South Texas. Discussion by W. Armstrong Price	960
Longwell, Chester R., Knopf, Adolph, and Flint, Richard F. Outlines of Physical Geology. Review by C. L. Dake	786
Los Angeles Basin, Pliocene Conglomerates of, and Their Paleogeographic Significance. By Everett C. Edwards	543
Louisiana, Discovery of Valentine (La Rose) Dome, by Reflection Seismograph. Geological Note by George S. Buchanan	

INDEX TO VOLUME 18

1729

Louisiana and Texas, Oil-Producing Horizons of Gulf Coast in. By Alexander Deussen	500
Louisiana and Texas Salt-Dome Cap-Rock Minerals. By Marcus A. Hanna and Albert G. Wolf	212
Low-Angle Overthrust Faulting, Mechanics of, as Illustrated by Cumberland Thrust Block, Virginia, Kentucky, and Tennessee. By John L. Rich	1584
Lowe, Ephraim Noble. Memorial by William Clifford Morse	428
Lucke, John B. A Study of Barnegat Inlet. Review by John L. Rich	1208
Lugn, A. L. Pre-Pennsylvanian Stratigraphy of Nebraska	1597
McFaddin-O'Conner, Greta, Fox, Refugio, White Point, and Sargent Fields, Texas. By A. E. Getzendaner	519
Macfadyen, W. A. The Geology of British Somaliland. Review by Margaret C. Cobb	1212
Magnetic and Torsion-Balance Survey of Münich Tertiary Basin, Bavaria. By Donald C. Barton	69
Magnetic Vector Study of Kentucky and Southern Michigan. By W. P. Jenny	97
Martin, Helen M. Review of Oil and Gas Fields of Michigan, by Robert B. Newcombe	149
Measurement of Permeability of Porous Media. By R. D. Wyckoff, H. G. Botset, M. Muskat, and D. W. Reed	161
Mechanics of Low-Angle Overthrust Faulting as Illustrated by Cumberland Thrust Block, Virginia, Kentucky, and Tennessee. By John L. Rich	1584
Mediterranean and Ponto-Caspian Types of Oil Deposits. By Stanislav Zuber	760
Melcher, Arles Francis. Memorial by C. E. Van Orstrand	560
Membership Applications Approved for Publication	
154, 274, 384, 558, 672, 831, 963, 1099, 1381, 1552, 1717	
Membership List	390, 1219
Memorial	277, 428, 560, 715, 967, 1222, 1554
Mesozoic Rocks on West Side of Sacramento Valley, California, Preliminary Study of Source Beds in Late. By Parker D. Trask and Harald E. Hammar	1346
Michigan, Oil and Gas Fields of. By Robert B. Newcombe. Review by Helen M. Martin	149
—, Southern, and Kentucky, Magnetic Vector Study of. By W. P. Jenny	97
Mid-Continent Region, Relation of Ouachita Belt of Paleozoic Rocks to Oil and Gas Fields of. By Hugh D. Miser	1059
Miller, J. Charles, and Avery, C. Dwight. Relationship of Geology to Unit Operation of Oil and Gas Fields Involving Government Lands	1454
Mineralogy of Sedimentary Rocks—A Series of Essays and a Bibliography. by P. G. H. Boswell. Review by G. S. Dillé	267
Minutes of Business Meeting, Baker Hotel, Dallas, Texas, March 22-24, 1934.	
The Association Round Table	684
Miser, Hugh D. Carboniferous Rocks of Ouachita Mountains	971
—. Relation of Ouachita Belt of Paleozoic Rocks to Oil and Gas Fields of Mid-Continent Region	1059
Mississippian of Colorado. By A. E. Brainerd and J. Harlan Johnson	531
Mississippian Rocks in Trans-Pecos Texas, Notes on Upper. Geological Note by Philip B. King	1537
Missouri, Arkansas, and Oklahoma, Osage Formations of Southern Ozark Region. By L. M. Cline	1132
Montana, Section of Paleozoic and Mesozoic Rocks Measured at Cinnabar Mountain, Park County, and at Mount Everts, Yellowstone National Park, Wyoming. Geological Note by Charles W. Wilson, Jr.	368
Moore, P. D., and Link, Theodore. Structure of Turner Gas and Oil Field, Alberta	1417
Moore, T. V., Deussen, Alexander, Brace, O. L., Pepperberg, Leon J., Thompson, W. C., Clark, S. K., and Wilde, Jr., H. D. Factors Governing Estimation of Recoverable Oil Reserves in Sand Fields. Discussion	1078
Moos, A., Steinbrecher, H., and Stutzer, O. <i>Deutsches Erdöl, II.</i> Review by Donald C. Barton	1092
Morse, William Clifford. Memorial of Ephraim Noble Lowe	428
Mount Everts, Yellowstone National Park, Wyoming, and Cinnabar Mountain, Park County, Montana, Section of Paleozoic and Mesozoic Rocks	

INDEX TO VOLUME 18

Measured at. Geological Note by Charles W. Wilson, Jr.	368
Muir, J. Lawrence. Anhydrite-Gypsum Problem of Blaine Formation, Oklahoma	1297
Münich Tertiary Basin, Bavaria, Magnetic and Torsion-Balance Survey of. By Donald C. Barton	69
Muskat, M., Wyckoff, R. D., Botset, H. G., and Reed, D. W. Measurement of Permeability of Porous Media.	161
National Oil Scouts Association Year Book, 1934. Review by Jesse L. Bullard	1213
Natural Gas in Australia and New Guinea. By W. G. Woolnough.	226
— in Poland. By K. Tolwinski	892
— in Roumania. Geology of. By Ionel I. Gardescu	871
Natural Gas and Oil in India. By D. Dale Condit	283
Natural Gas and Petroleum in Poland. Volume II—Boryslaw. Part I, Geology. Part II, Production Statistics. By K. Tolwinski. Review by Charles Bohdanowicz.	1713
Natural Gas Fields of Burma. By L. Dudley Stamp.	315
Natural Gas Occurrences in Russia (U.S.S.R.). By Charles Bohdanowicz	746
— of Germany. By H. Stille and H. Schlüter	719
Nebraska, Pre-Pennsylvanian Stratigraphy of. By A. L. Lugo	1507
Nettleton, L. L. Fluid Mechanics of Salt Domes	1175
— Fluid Mechanics of Salt Domes. Discussion	1712
Newcombe, Robert B. Oil and Gas Fields of Michigan. Review by Helen M. Martin	149
New Guinea and Australia, Natural Gas in. By W. G. Woolnough	226
Nicolesco, C. P. <i>Gisement pétroliers de Iraq</i> (The Petroliferous Beds of Iraq). Review by H. de Cizancourt	381
Nineteenth Annual Meeting, The American Association of Petroleum Geologists, Baker Hotel, Dallas, Texas, March 22-24, 1934. The Association Round Table.	154, 274, 673
Nolan, P. E. Memorial of Irving McKay Streeter	277
Notes on Origin of Oil in Kentucky. By William L. Russell.	1126
— on Upper Mississippian Rocks in Trans-Pecos Texas. Geological Note by Philip B. King	1537
Occurrence of Siderite in Cap Rock at Carlos Dome, Grimes County, Texas. Geological Note by F. W. Rolhausen	543
Oil in Kentucky, Notes on Origin of. By William L. Russell	1126
—, Physical Characteristics of Bradford Sand, Bradford Field, Pennsylvania, and Relation to Production of. By Charles R. Fettke	191
—, Tectonics and Paleogeography of Basin System of Hungary as Elucidated by Drilling for. By L. De Lóczy	925
Oil Accumulation, Rôle of Cap Rock in. Discussion by C. L. Dake and L. F. Dake	1086
Oil and Gas, Coalification Theory of Origin of. Discussion by F. M. Van Tuyl and Ben H. Parker	1547
Oil and Gas in Western Canada (2d ed.). By G. S. Hume. Review by Theodore A. Link	551
Oil and Gas Fields of Michigan. By Robert B. Newcombe. Review by Helen M. Martin	149
— of Mid-Continent Region, Relation of Ouachita Belt of Paleozoic Rocks to. By Hugh D. Miser	1059
Oil and Gas Occurrences, European, and Their Relationship to Structural Conditions. By H. Stille and H. Schlüter	736
Oil and Natural Gas in India. By D. Dale Condit	283
Oil-Bearing Deposits in Ponto-Caspian Countries, Paleogeography of. By Stanislav Zuber	777
Oil Deposits, Ponto-Caspian and Mediterranean Types of. By Stanislav Zuber	760
Oil Field, Kettleman Hills, California, Subsurface Stratigraphy of. By Paul P. Goudkoff	435
Oil Field Development (2d ed.). Petroleum Production Engineering. By Lester Charles Uren. Review by Lyndon L. Foley	961
Oil Fields, Tectonics of Southeastern Caucasus and Its Relation to the Productive. By I. M. Goukkin	603

INDEX TO VOLUME 18

1731

Oil Finding, Two Decades of Progress in the Art. Geological Note by Alexander Deussen	942
Oil Possibilities of Belgium and Belgian Congo. By Sylvain J. Pirson	1160
Oil-Producing Horizons of Gulf Coast in Texas and Louisiana. By Alexander Deussen	500
Oil Production, Jamin Effect in. Discussion by J. Versluyss	547
Oil Reserves in Sand Fields, Factors Governing Estimation of Recoverable. By O. L. Brace	343
—, Discussion by Alexander Deussen, O. L. Brace, Leon J. Pepperberg, W. C. Thompson, S. K. Clark, H. D. Wilde, Jr., and T. V. Moore	1078
Oklahoma, Anhydrite-Gypsum Problem of Blaine Formation. By J. Lawrence Muir	1297
—, Correction to Stratigraphy of Hoxbar Formation. Discussion by C. W. Tomlinson	1083
—, En Échelon Faults in. By William B. Kramer	243
—, Granite and Limestone Velocity Determinations in Arbuckle Mountains. By B. B. Weatherby, W. T. Born, and R. L. Harding	106
—, Missouri, and Arkansas, Osage Formations of Southern Ozark Region. By L. M. Cline	1132
—, Overthrusting in Arbuckle Mountains. By Robert H. Dott	567
Oklahoma and Arkansas, Age of Jackfork and Stanley Formations of Ouachita Geosyncline, as Indicated by Plants. By David White	1010
Oklahoma and Arkansas Coal Fields, Correlations of Pennsylvanian Strata in. By T. A. Hendricks and C. B. Read	1050
Oklahoma City Anticline, Tectonics of. By Lyndon L. Foley	251
Organic Content of Rocks, Some Characteristics of. By William L. Russell	1103
Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas. By N. W. Bass.	1313
—. Discussion by Russell S. Tarr	1710
Origin of Oil and Gas, Coalification Theory of. Discussion by F. M. Van Tuyl and Ben H. Parker	1547
Origin of Oil in Kentucky, Notes on. By William L. Russell	1126
Origin of the Anhydrite Cap Rock of American Salt Domes. By Marcus I. Goldman. Review by Donald C. Barton	269
Orogentheorie, <i>Die</i> . By L. Kober. Review by Walter H. Bucher	824
Osage Formations of Southern Ozark Region, Missouri, Arkansas, and Oklahoma. By L. M. Cline	1132
Osborne, Clarence B. Memorial of Ira Abraham Williams	967
Ouachita Belt of Paleozoic Rocks, Relation to Oil and Gas Fields of Mid-Continent Region. By Hugh D. Miser	1059
Ouachita Geosyncline, Arkansas and Oklahoma, Age of Jackfork and Stanley Formations of, as Indicated by Plants. By David White	1010
Ouachita Mountains, Carboniferous Rocks of. By Hugh D. Miser	971
Ouachitas, Carboniferous Stratigraphy of the, with Special Study of the Bendian. By Bruce H. Harlon	1018
Outlines of Physical Geology. By Chester R. Longwell, Adolph Knopf, and Richard F. Flint. Review by C. L. Daké	960
Overthrust Faulting, Mechanics of Low-Angle, as Illustrated by Cumberland Thrust Block, Virginia, Kentucky, and Tennessee. By John L. Rich	1584
Overthrusting in Arbuckle Mountains, Oklahoma. By Robert H. Dott	567
Owen, Ed. W. Review of The Geology of Texas, Vol. I, Stratigraphy, by E. H. Sellards, W. S. Adkins, and F. B. Plummer	554
Ozark Region, Missouri, Arkansas, and Oklahoma, Osage Formations of Southern. By L. M. Cline	1132
Paleogeographic Significance of Pliocene Conglomerates of Los Angeles Basin. By Everett C. Edwards	786
Paleogeography of Oil-Bearing Deposits in Ponto-Caspian Countries. By Stanislav Zuber	777
Paleogeography and Tectonics of Basin System of Hungary as Elucidated by Drilling for Oil. By L. De Lóczy	925
Paleozoic and Mesozoic Rocks, Section Measured at Cinnabar Mountain, Park County, Montana, and at Mount Everts, Yellowstone National Park,	

Wyoming. Geological Note by Charles W. Wilson, Jr.	368
Paleozoic Rocks, Relation of Ouachita Belt of, to Oil and Gas Fields of Mid-Continent Region. By Hugh D. Miser	1059
Parker, Ben H., and Sanders, C. W. Geology of Two Buttes Dome in Southeastern Colorado. Discussion	1544
Parker, Ben H., and Van Tuyl, F. M. Coalification Theory of Origin of Oil and Gas. Discussion	1547
Past Presidents of the Association. The Association Round Table	832
Pecan Gap Chalk, Correlation of, in Texas. By Alva C. Ellison and John Teagle	1506
Pennsylvania, Physical Characteristics of Bradford Sand, Bradford Field, and Relation to Production of Oil. By Charles R. Fettke	191
Pennsylvanian Strata in Arkansas and Oklahoma Coal Fields, Correlations of. By T. A. Hendricks and C. B. Read	1050
Pepperberg, Leon J., Deussen, Alexander, Brace, O. L., Thompson, W. C., Clark, S. K., Wilde, Jr., H. D., and Moore, T. V. Factors Governing Estimation of Recoverable Oil Reserves in Sand Fields. Discussion	1078
Periodical Library Service	1215
Permeability of Porous Media, Measurement of. By R. D. Wyckoff, H. G. Botset, M. Muskat, and D. W. Reed	161
Permian Ledge-Makers in Concho County, Texas. By William Kramer	1577
Petroleum and Natural Gas in Poland. Volume II—Boryslaw. Part I, Geology. Part II, Production Statistics. By K. Tolwinski. Review by Charles Bohdanowicz	1713
Petroleum Development and Technology, 1934. By Petroleum Division, Trans. Amer. Inst. Min. Met. Eng., Vol. 107. Review by Robert H. Dott	1378
Petroleum Division, Trans. Amer. Inst. Min. Met. Eng., Vol. 107. Petroleum Development and Technology, 1934. Review by Robert H. Dott	1378
Petroleum Production Engineering. Oil Field Development (ad ed.). By Lester Charles Uren. Review by Lyndon L. Foley	961
Petroleum Resources of Japan. By Yoshinosuki Chitani	908
Physical Characteristics of Bradford Sand, Bradford Field, Pennsylvania, and Relation to Production of Oil. By Charles R. Fettke	191
Phosphoria and Dinwoody Tongues in Lower Chugwater of Central and Southeastern Wyoming. By Horace D. Thomas	1655
Physics of the Earth—VI. Seismology. By the Subsidiary Committee on Seismology, Division of Physical Sciences, with the Co-operation of the Division of Geology and Geography, and the American Geophysical Union. Review by B. B. Weatherby	1205
Pierce, W. G., and Dane, Carle H. Fossil Sink Holes in Cretaceous Beds of Prowers County, Colorado	1493
Pirson, Sylvain J. Oil Possibilities of Belgium and Belgian Congo	1160
Pliocene Conglomerates of Los Angeles Basin and Their Paleogeographic Significance. By Everett C. Edwards	786
Plummer, F. B., Sellards, E. H., and Adkins, W. S. The Geology of Texas, Vol. I, Stratigraphy. Review by Ed. W. Owen	554
Poland, Natural Gas in. By K. Tolwinski	892
—, Petroleum and Natural Gas in. Volume II—Boryslaw. Part I, Geology. Part II, Production Statistics. By K. Tolwinski. Review by Charles Bohdanowicz	1713
Ponto-Caspian and Mediterranean Types of Oil Deposits. By Stanislav Zuber	760
Ponto-Caspian Countries, Paleogeography of Oil-Bearing Deposits in. By Stanislav Zuber	777
Porous Media, Measurement of Permeability of. By R. D. Wyckoff, H. G. Botset, M. Muskat, and D. W. Reed	161
Portable Sedimentary Laboratory. Geological Note by F. R. S. Henson	1705
Preliminary Study of Source Beds in Late Mesozoic Rocks on West Side of Sacramento Valley, California. By Parker D. Trask and Harald E. Hammar	1346
Pre-Pennsylvanian Stratigraphy of Nebraska. By A. L. Lugin	1597
Presidential Address: The New Challenge. Frank Rinker Clark. The Association Round Table	673
Presidents of the Association	832

INDEX TO VOLUME 18

1733

Price, W. Armstrong. Craters Formed by Air Blowers. Geological Note 813
 ——. Lissie Formation and Beaumont Clay in South Texas. Discussion 948
 ——. Thickness and Depth of Strata. Discussion 817
 Principles of Historical Geology from the Regional Point of View. By Richard Montgomery Field. Review by Robert Roth 553
 Proceedings World Petroleum Congress. Review by W. P. Haynes 822
 Prowers County, Colorado, Fossil Sink Holes in Cretaceous Beds of. By Carle H. Dane and W. G. Pierce 1493

Radio, Earth and the Stars. By Harlan True Stetson. Review by C. E. Van Orstrand 1209
 Radioactivity of Soil Gases. By Lynn G. Howell 63
 Rattlesnake Hills Gas Field, Benton County, Washington. By A. A. Hammer 847
 Read, C. B., and Hendricks, T. A. Correlations of Pennsylvanian Strata in Arkansas and Oklahoma Coal Fields 1050
 Recent Publications 152, 272, 382, 554, 828, 962, 1097, 1214, 1370, 1551, 1716
 Recoverable Oil Reserves in Sand Fields, Factors Governing Estimation of. By O. L. Brace 343
 Reed, D. W., Wyckoff, R. D., Botset, H. G., and Muskat, M. Measurement of Permeability of Porous Media 161
 Reed, R. D. Review of The Jurassic System in Great Britain, by W. J. Arkell 268
 ——. Review of *Untersuchungen über die Sedimentationsverhältnisse des Schwarzenmeeres und ihre Anwendung auf das nordkaukasische Erdölgebiet* (Investigations of Conditions of Sedimentation in the Black Sea and Their Application to the Oil Fields North of the Caucasus), by Dora Wolansky 550
 Reflection Seismograph, Discovery of Valentine (La Rose) Dome, Louisiana, by. Geological Note by George S. Buchanan 543
 Refugio, McFaddin-O'Conner, Greta, Fox, White Point, and Saxed Fields, Texas. By A. E. Getzendaner 519
 Reich, Hermann. *Angewandte Geophysik für Bergleute und Geologen, I Teil* (Practical Geophysics for Engineers and Geologists, Part 1). Review by L. Y. Faust 149
 Relation of Ouachita Belt of Paleozoic Rocks to Oil and Gas Fields of Mid-Continent Region. By Hugh D. Miser 1059
 Relations of Geophysics to Geology. By Paul Weaver 3
 Relationship of Geology to Unit Operation of Oil and Gas Fields Involving Government Lands. By C. Dwight Avery and J. Charles Miller 1454
 Report on Aerial Survey Operations in Australia During 1932. By W. G. Woolnough. Review by W. P. Woodring 380
 Republic of Austria and Neighboring Territory, Geological Map of the. Hermann Vettler, compiler. Review by Walter M. Small 1375
 Research Committee. By Donald C. Barton. The Association Round Table 834
 Reviews 149, 267, 380, 550, 822, 960, 1092, 1205, 1374, 1549, 1713
 Rich, John L. Corrections for Temperature in Barometric Surveying. Geological Note 133
 ——. Mechanics of Low-Angle Overthrust Faulting as Illustrated by Cumberland Thrust Block, Virginia, Kentucky, and Tennessee 1584
 ——. Review of A Study of Barnegat Inlet, by John B. Lucke 1208
 Richards, Jr., G. L., and Richards, L. W. Geologic History at a Glance. Review by William S. Kew 1213
 Richards, L. W., and Richards, Jr., G. L. Geologic History at a Glance. Review by William S. Kew 1213
 Roberts, John R. Memorial by Louis H. Evans 277
 Rôle of Cap Rock in Oil Accumulation. Discussion by C. L. Daké and L. F. Daké 1086
 Rolshausen, F. W. Occurrence of Siderite in Cap Rock at Carlos Dome, Grimes County, Texas. Geological Note 543
 Rosaire, E. E., and Adler, Joseph L. Applications and Limitations of Dip Shooting 119
 Roth, Robert. Review of The Principles of Historical Geology from the Regional Point of View, by Richard Montgomery Field 553
 ——. Type Section of Hermosa Formation, Colorado. Geological Note 944
 Roumania, Geology of Natural Gas in. By Ionel I. Gardescu 871
 Russell, William L. Notes on Origin of Oil in Kentucky 1126

INDEX TO VOLUME 18

— Some Characteristics of Organic Content of Rocks 1103
 Russia (U.S.S.R.), Natural Gas Occurrences in. By Charles Bohdanowicz 746

Sacramento Valley, California, Preliminary Study of Source Beds in Late Mesozoic Rocks on West Side of. By Parker D. Trask and Harald E. Hammar 1346
 Salt Domes, Fluid Mechanics of. By L. L. Nettleton 1175
 — Discussion by L. L. Nettleton 1712

Salt Domes, Origin of the Anhydrite Cap Rock of American. By Marcus I. Goldman. Review by Donald C. Barton 269

Salt Water, Analyses of Woodbine Cores for Presence of. Geological Note by R. H. Fash 265

Salt-Dome Cap-Rock Minerals, Texas and Louisiana. By Marcus A. Hanna and Albert G. Wolf 212

San Joaquin Clay, California. By W. F. Barbat and John Galloway 476

Sand Fields, Factors Governing Estimation of Recoverable Oil Reserves in. By O. L. Brace 343

Sanders, C. W. Geology of Two Buttes Dome in Southeastern Colorado 860

Sanders, C. W., and Parker, Ben H. Geology of Two Buttes Dome in Southeastern Colorado. Discussion 1544

Saxet, McFaddin-O'Conner, Greta, Fox, Refugio, and White Point Fields, Texas. By A. E. Getzendaner 519

Scheib, Roberto. *Compilacion de los Estudios Geologicos Oficiales en Colombia, 1917-1933, Tomo I* (Compilation of the Official Geological Studies in Colombia, 1917 to 1933, Vol. I). Review by Robert H. Dott 1377

Schlüter, H., and Stille, H. European Oil and Gas Occurrences and Their Relationship to Structural Conditions 736

— Natural Gas Occurrences of Germany 719

Sea Water, Base Exchange in Relation to Composition of Clay with Special Reference to Effect of. By W. P. Kelley and G. F. Liebig, Jr. 358

Section of Paleozoic and Mesozoic Rocks Measured at Cinnabar Mountain, Park County, Montana, and at Mount Everts, Yellowstone National Park, Wyoming. Geological Note by Charles W. Wilson, Jr. 368

Sedimentary Laboratory, Portable. Geological Note by F. R. S. Henson 1705

Sedimentary Rocks, on the Mineralogy of—A Series of Essays and a Bibliography. By P. G. H. Boswell. Review by G. S. Dillé 267

Seismograph, Discovery of Valentine (La Rose) Dome, Louisiana, by Reflection. Geological Note by George S. Buchanan 543

Sellards, E. H., Adkins, W. S., and Plummer, F. B. The Geology of Texas, Vol. I, Stratigraphy. Review by Ed. W. Owen 554

Seyer, W. F. Conversion of Fatty and Waxy Substances into Petroleum Hydrocarbons. Discussion by Donald C. Barton 143

Seymour, D. Bruce. Memorial by R. M. Barnes 1222

Shutt, Roscoe E. Memorial of Thomas Kennerly Hornsberger 1554

Siderite, Occurrence of, in Cap Rock at Carlos Dome, Grimes County, Texas. Geological Note by F. W. Rolshausen 543

Small, Walter M. Review of Geological Map of the Republic of Austria and Neighboring Territory, compiled by Hermann Vettlers 1375

Small Scale Geological Maps, Catalogue of, 1933. By Walter H. Bucher, *et al.* Review by A. I. Levorsen 1208

Snider, L. C. Review of Igneous Rocks and the Depths of the Earth, by Reginald Aldworth Daly 151

Soil Gases, Radioactivity of. By Lynn G. Howell 63

Some Characteristics of Organic Content of Rocks. By William L. Russell 1103

Source Beds in Late Mesozoic Rocks on West Side of Sacramento Valley, California, Preliminary Study of. By Parker D. Trask and Harald E. Hammar 1346

Stamp, L. Dudley. Natural Gas Fields of Burma 315

Stanley and Jackfork Formations of Ouachita Geosyncline, Arkansas and Oklahoma, Age of, as Indicated by Plants. By David White 1010

Starke, Eric A. Memorial by W. S. W. Kew 967

Stauff, J. Lauer. Memorial by Oliver B. Hopkins 715

Steinbrecher, H., Moos, A., and Stutzer, O. *Deutsches Erdöl, II*. Review by Donald C. Barton 1092

Stetson, Harlan True. Earth, Radio and the Stars. Review by C. E. Van Orstrand 1209

Stevens, George D., and Goldston, W. L., Esperson Dome, Liberty County, Texas 1632

Stewart, Ralph. Review of The Deformation of the Earth's Crust, by Walter H. Bucher 1093

Stille, H., and Schlüter, H. European Oil and Gas Occurrences and Their Relationship to Structural Conditions 736

—. Natural Gas Occurrences of Germany 719

Stratigraphic Thickness Exposed Between Two Dips, Formulas for Calculating. Geological Note by E. L. Ickes 139

Stratigraphy of Hoxbar Formation, Oklahoma, Correction to. Discussion by C. W. Tomlinson 1083

—. of Kettleman Hills Oil Field, California, Subsurface. By Paul P. Goudkoff 435

—. Pre-Pennsylvanian, of Nebraska. By A. L. Lumm 1597

—. The Geology of Texas, Vol. I. By E. H. Sellards, W. S. Adkins, and F. B. Plummer. Review by Ed. W. Owen 554

Streeter, Irving McKay. Memorial by P. E. Nolan 277

Structural Conditions, European Oil and Gas Occurrences and Their Relationship to. By H. Stille and H. Schlüter 736

Structure of Turner Valley Gas and Oil Field, Alberta. By Theodore Link and P. D. Moore 1417

Study of Barnegat Inlet. By John B. Lucke. Review by John L. Rich 1208

Stutzer, O., Moos, A., and Steinbrecher, H. *Deutsches Erdöl, II.* Review by Donald C. Barton 1092

Subsurface Stratigraphy of Kettleman Hills Oil Field, California. By Paul P. Goudkoff 435

Supplementary Membership List, September 1, 1934. The Association Round Table 1219

Symposium on Geophysics: Foreword. By B. B. Weatherby 1

Tarr, Russell S. An Explanation for Large Amounts of Gas in Anderson and Leon Counties, Texas. Geological Note 263

—. Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas. Discussion 1710

Teagle, John, and Ellisor, Alva C. Correlation of Pecan Gap Chalk in Texas 1506

Tectonics of Oklahoma City Anticline. By Lyndon L. Foley 251

—. of Southeastern Caucasus and Its Relation to the Productive Oil Fields. By I. M. Goubkin 603

Tectonics and Paleogeography of Basin System of Hungary as Elucidated by Drilling for Oil. By L. De Lóczy 925

Temperature, Corrections for, in Barometric Surveying. Geological Note by John L. Rich 133

Tennessee, Virginia, and Kentucky, Mechanics of Low-Angle Overthrust Faulting as Illustrated by Cumberland Thrust Block. By John L. Rich 1584

Terminology, Difficulty of Using Cartographic, in Historical Geology. Geological Note by R. M. Kleinpell 374

Tertiary Faunas. Vol. II, The Sequence of Tertiary Faunas. By A. Morley Davies. Review by Alva C. Ellisor 1206

Texas, An Explanation for Large Amounts of Gas in Anderson and Leon Counties. Geological Note by Russell S. Tarr 263

—. Correlation of Pecan Gap Chalk in. By Alva C. Ellisor and John Teagle 1506

—. Esperson Dome, Liberty County. By W. L. Goldston and George D. Stevens 1632

—. Fredericksburg-Washita (Edwards-Georgetown) Contact in Edwards Plateau Region. Geological Note by William H. Curry, Jr. 1698

—. Lissie Formation and Beaumont Clay in South. Discussion by W. Armstrong Price 948

—. Notes on Upper Mississippian Rocks in Trans-Pecos. Geological Note by Philip B. King 1537

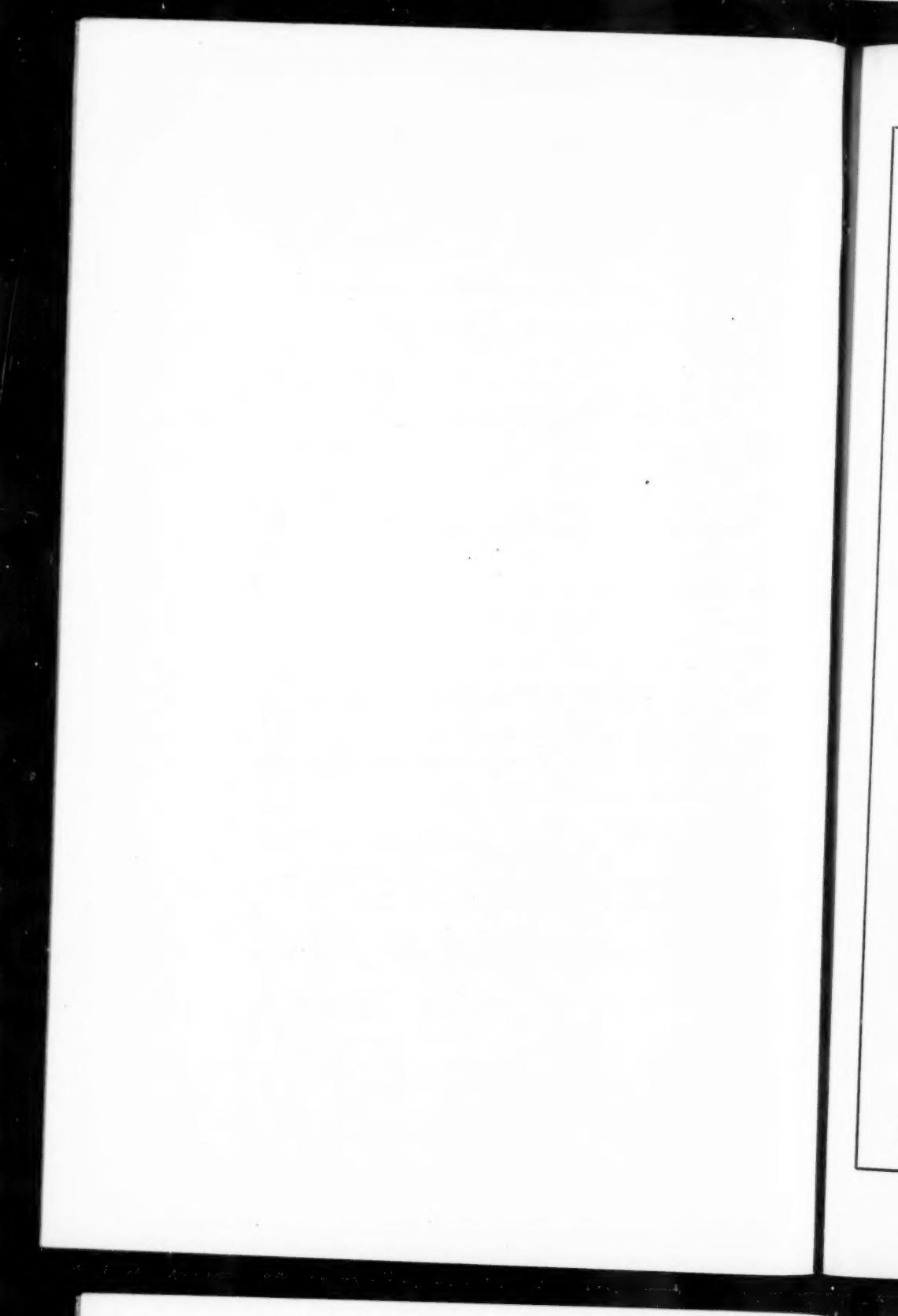
—. Occurrence of Siderite in Cap Rock at Carlos Dome, Grimes County. Geological Note by F. W. Rolshausen 543

_____, Permian Ledge-Makers in Concho County. By William Kramer	1577
_____, The Geology of, Vol. I, Stratigraphy. By E. H. Sellards, W. S. Adkins, and F. B. Plummer. Review by Ed. W. Owen	554
Texas and Louisiana, Oil-Producing Horizons of Gulf Coast in. By Alexander Deussen	500
Texas and Louisiana Salt-Dome Cap-Rock Minerals. By Marcus A. Hanna and Albert G. Wolf	212
Thickness and Depth of Strata. Discussion by W. Armstrong Price	817
Thomas, Horace D. Phosphoria and Dinwoody Tongues in Lower Chugwater of Central and Southeastern Wyoming	1655
Thompson, W. C., Deussen, Alexander, Brace, O. L., Pepperberg, Leon J., Clark, S. K., Wilde, Jr., H. D., and Moore, T. V. Factors Governing Estimation of Recoverable Oil Reserves in Sand Fields. Discussion	1078
Tolwinski, K. Natural Gas in Poland	892
_____, Petroleum and Natural Gas in Poland. Volume II—Boryslaw. Part I. Geology. Part II, Production Statistics. Review by Charles Bohdanowicz	1713
Tomlinson, C. W. Correction to Stratigraphy of Hoxbar Formation, Oklahoma. Discussion	1083
Torsion-Balance and Magnetic Survey of München Tertiary Basin, Bavaria. By Donald C. Barton	69
Trans-Pecos Texas, Notes on Upper Mississippian Rocks in. Geological Note by Philip B. King	1537
Trask, Parker D., and Hammar, Harald E. Preliminary Study of Source Beds in Late Mesozoic Rocks on West Side of Sacramento Valley, California	1346
Turner Valley Gas and Oil Field, Alberta, Structure of. By Theodore Link and P. D. Moore	1417
Two Buttes Dome in Southeastern Colorado, Geology of. By C. W. Sanders	860
_____. Discussion by Ben H. Parker and C. W. Sanders	1544
Two Decades of Progress in the Art of Oil Finding. Geological Note by Alexander Deussen	942
Type Section of Hermosa Formation, Colorado. Geological Note by Robert Roth	944
Unit Operation of Oil and Gas Fields Involving Government Lands, Relationship of Geology to. By C. Dwight Avery and J. Charles Miller	1454
Untersuchungen über die Sedimentationsverhältnisse des Schwarzenmeeres und ihre Anwendung auf das nordkaukasische Erdölgebiet (Investigations of Conditions of Sedimentation in the Black Sea and Their Application to the Oil Fields North of the Caucasus). By Dora Wolansky. Review by R. D. Reed	550
Upper Mississippian Rocks in Trans-Pecos Texas, Notes on. Geological Note by Philip B. King	1537
Uren, Lester Charles. Petroleum Production Engineering. Oil Field Development (2d. ed.). Review by Lyndon L. Foley	961
Valentine (La Rose) Dome, Louisiana, Discovery of, by Reflection Seismograph. Geological Note by George S. Buchanan	543
Van Orstrand, C. E. Memorial of Arles Francis Melcher	560
_____. Review of Earth, Radio and the Stars, by Harlan True Stetson	1209
_____. Some Possible Applications of Geothermics to Geology	13
Van Tuyl, F. M., and Parker, Ben H. Coalification Theory of Origin of Oil and Gas. Discussion	1547
Velocity Determinations, Granite and Limestone, in Arbuckle Mountains, Oklahoma. By B. B. Weatherby, W. T. Born, and R. L. Harding	106
Ver Wiebe, Walter August. Historical Geology. Review by Roy H. Hall	1550
Versluys, J. Jamin Effect in Oil Production. Discussion	547
Vetters, Hermann, compiler. Geological Map of the Republic of Austria and Neighboring Territory. Review by Walter M. Small	1375
Virginia, Kentucky, and Tennessee, Mechanics of Low-Angle Overthrust Faulting as Illustrated by Cumberland Thrust Block. By John L. Rich	1584
Washington, Rattlesnake Hills Gas Field, Benton County. By A. A. Hammer	847
Weatherby, B. B. Foreword to Symposium on Geophysics	1

INDEX TO VOLUME 18

1737

—. Review of Physics of the Earth—VI. Seismology, by the Subsidiary Committee on Seismology, Division of Physical Sciences, with the Coöperation of the Division of Geology and Geography, and the American Geophysical Union	1205
Weatherby, B. B., Born, W. T., and Harding, R. L. Granite and Limestone Velocity Determinations in Arbuckle Mountains, Oklahoma. By B. B. Weatherby, W. T. Born, and R. L. Harding	106
Weaver, Paul. Relations of Geophysics to Geology	3
Webb, J. B., and Hertlein, L. G. Zones in Alberta Shale in Foothills of Southwestern Alberta	1387
White, David. Age of Jackfork and Stanley Formations of Ouachita Geosyncline, Arkansas and Oklahoma, as Indicated by Plants	1010
White Point, McFaddin-O'Conner, Greta, Fox, Refugio, and Sasket Fields, Texas. By A. E. Getzendaner	519
Wilde, Jr., H. D., Deussen, Alexander, Brace, O. L., Pepperberg, Leon J., Clark, S. K., Thompson, W. C., and Moore, T. V. Factors Governing Estimation of Recoverable Oil Reserves in Sand Fields. Discussion	1078
Williams, Ira Abraham. Memorial by Clarence B. Osborne	967
Willis, Bailey and Robin. Geologic Structures, 3d ed. Review by J. V. Howell	1549
Wilson, Jr., Charles W. Section of Paleozoic and Mesozoic Rocks Measured at Cinnabar Mountain, Park County, Montana, and at Mount Everts, Yellowstone National Park, Wyoming. Geological Note	368
Wolansky, Dora. <i>Untersuchungen über die Sedimentationsverhältnisse des Schwarzenmeeres und ihre Anwendung auf das nordkaukasische Erdölgebiet</i> (Investigations of Conditions of Sedimentation in the Black Sea and Their Application to the Oil Fields North of the Caucasus). Review by R. D. Reed	550
Wolf, Albert G., and Hanna, Marcus A. Texas and Louisiana Salt-Dome Cap-Rock Minerals	212
Woodbine Cores, Analyses of, for Presence of Salt Water. Geological Note by R. H. Fash	265
Woodring, W. P. Review of Report on Aerial Survey Operations in Australia During 1932, by W. G. Woolnough	380
Woolnough, W. G. Natural Gas in Australia and New Guinea	226
—. Report on Aerial Survey Operations in Australia During 1932. Review by W. P. Woodring	380
World Petroleum Congress, Proceedings. Review by W. P. Haynes	822
Wyckoff, R. D., Botset, H. G., Muskat, M., and Reed, D. W. Measurement of Permeability of Porous Media	161
Wyoming, Phosphoria and Dinwoody Tongues in Lower Chugwater of Central and Southeastern. By Horace D. Thomas	1655
—. Section of Paleozoic and Mesozoic Rocks Measured at Cinnabar Mountain, Park County, Montana, and at Mount Everts, Yellowstone National Park. Geological Note by Charles W. Wilson, Jr.	368
Zones in Alberta Shale in Foothills of Southwestern Alberta. By J. B. Webb and L. G. Hertlein	1387
Zuber, Stanislav. Paleogeography of Oil-Bearing Deposits in Ponto-Caspian Countries	777
—. Ponto-Caspian and Mediterranean Types of Oil Deposits	760



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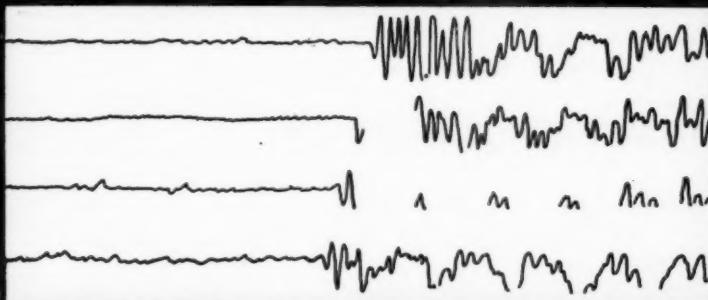
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CONTENTS

Heavy Mineral Studies on Correlation of Sands at Kettleman Hills, California	
By M. N. Bramlette	1559
Permian Ledge-Makers in Concho County, Texas	
By William Kramer	1577
Mechanics of Low-Angle Overthrust Faulting as Illustrated by Cumberland	
Thrust Block, Virginia, Kentucky, and Tennessee	
By John L. Rich	1584
Pre-Pennsylvanian Stratigraphy of Nebraska	
By A. L. Lugin	1597
Esperson Dome, Liberty County, Texas	
By W. L. Goldston, Jr., and George D. Stevens	1632
Phosphoria and Dinwoody Tongues in Lower Chugwater of Central and	
Southeastern Wyoming	
By Horace D. Thomas	1655
GEOLOGICAL NOTES	
Fredericksburg-Washita (Edwards-Georgetown) Contact in Edwards Plateau Re-	
gion of Texas	
William H. Curry, Jr.	1698
Portable Sedimentary Laboratory	
F. R. S. Henson	1705
DISCUSSION	
Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas	
By Russell S. Tarr	1710
Fluid Mechanics of Salt Domes	
L. L. Nettleton	1712
REVIEWS AND NEW PUBLICATIONS	
Petroleum and Natural Gas in Poland. Volume II. Boryslaw. Part I, Geology.	
Part II, Production Statistics	
K. Tolwinski	1713
(Charles Bohdanowicz)	1716
Recent Publications	
THE ASSOCIATION ROUND TABLE	
Membership Applications Approved for Publication	1717
Association Committees	1718
AT HOME AND ABROAD	
Current News and Personal Items of the Profession	1719
INDEX TO VOLUME 18	
	1721

Articles for January *Bulletin*

Influence of Geological Factors on Longitudinal Seismic Velocities
By B. B. WEATHERBY and L. Y. FAUST

Effect of Moisture Upon Velocity of Elastic Waves in Amherst Sandstone
By W. T. BORN and J. E. OWEN

Recent Developments in Gravity Prospecting in Gulf Coast
By OLAF F. SUNDT

Prediction of Overhang at Barbers Hill, Chambers County, Texas: Study in Quantitative Calculations from Torsion-Balance Data
By DONALD C. BARTON

Study of Structure of Suwa Basin, Japan, by Torsion Balance
By M. MATSUYAMA, Y. FUJITA, and H. HIGASHINAKA

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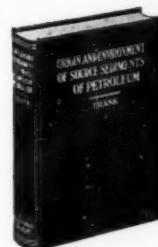
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		L. C. Morgan	ix		

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	PAGE		PAGE		PAGE
Appalachian	xiv	Kansas	xiii	Shawnee	xiii
Dallas	xiv	North Texas	xiv	Shreveport	xiii
East Texas	xiv	Oklahoma City	xiii	Stratigraphic	xiii
Fort Worth	xiv	Petroleum Geophysicists	xiv	Tulsa	xiii
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